Young children's understanding of science in 4 domains and its development through a constructivist approach to teaching.

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Abstract

This thesis reports work which attempted to explore the nature and extent of young children's (age 5-11) understanding of four domains of science - light, electricity, processes of life and astronomy. In each of these domains, an intervention based on constructivist principles was also conducted in conjunction with the existing class teachers to explore what potential this approach had as an effective pedagogy for primary science education.

This research was undertaken under the aegis of the Science Process and Concept Exploration (SPACE) project from 1988-1992 and was a collaborative effort. The chosen domains were selected to represent a range of the sciences and to match the knowledge and expertise of the research team.

The methodology adopted for the work was a mix of qualitative and quantitative. Qualitative in that the study was essentially an empirical study attempting to describe what are the *features of* children's knowledge and understanding, and how it develops with an intervention. It was quantitative in that it has attempted to measure and quantify the main aspects of their thinking to provide a) a picture of the predominance (or not) of a particular concept; b) to enable some measure of the significance of any changes to be determined, and c) to explore inter-relationships in the ideas and concepts held by individual children.

The research reported here has successfully managed to document a large sample of children's ideas in these domains and extend our knowledge of their thinking at these ages. In addition, it has been able to show that the use of a constructivist pedagogy can have positive outcomes for children's learning.

In the final chapter, the data are summarised and explored to show that there is little evidence that children are using consistent or coherent theories, rather that their thinking is context specific. A further exploration of the data argues that there are four strands of thinking which contribute to the explanation of children's reasoning - Piagetian developmentalism, constructivism, commonsense realism and an examination of language and metaphor. It is argued that much greater research needs to be done on the use of language for the construction, interpretation and negotiation of meaning in the classroom to improve our understanding of the growth of scientific knowledge in the young child. Finally, a brief, reflective critique of constructivism, which has evolved during the conduct of this work, is provided to show that there are limits to the application of this theory in science education.

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1: Introduction

1.1. Children's thinking - issues and concerns.

What understanding of science concepts do young children, age 5-11, have and how can it be developed? The answer to these questions is of fundamental importance to all those working in primary science education and to others - such as nurses and doctors who have to explain to children what is wrong with their bodies. Yet little systematic research has been conducted to answer this question.

The most notable contributions are those of Piaget (1929) who explored the children's conception of the world; Gellert (1962) who examined what children knew and understood of their own bodies and Osborne (1985) who investigated children's (age 9-16) understanding of forces, electricity, matter and animals using interviews about instances of physical phenomena and questionnaires. Whilst this research provides a basic description of some of the features of children's understanding, it is by no means comprehensive and only provides a sketchy picture of a child's interpretation of physical and biological phenomena.

However, the predominant focus of researchers in exploring children's understanding of science has been its use to explore the ontogenesis of the children's thinking. Such a focus lead Piaget (1950) to develop a genetic epistemological account of the growth of intelligence which has had, and continues to have, a seminal influence throughout educational research and classroom practice. In the past 15 years, dissatisfaction with this structuralist aspect of Piagetian theory, and developmental psychology in general, has lead to the growth of a research paradigm known as 'constructivism'. Researchers working in this field see children as scientists who hold consistent theories (Gilbert, Osborne, & Fensham, 1982; Driver, 1983) which are described as 'alternative frameworks' (Driver & Easley, 1978). These researchers portray the growth of the child's understanding as a process of theory restructuring and the most substantive evidence for this view is based on the work of Carey (1985) who undertook a detailed study of the growth of children's biological knowledge from age 5-11. She argued that children are possibly born with an intuitive biological knowledge which is restructured between these ages. She maintains that her evidence shows that the process occurs because of an increase in the child's biological knowledge, and not because of any maturation in the mental processes available to the child. This view is supported by Vosniadou (1991) who contends that her study of the development of children's astronomical knowledge provides further evidence to support Carey's thesis, though her methodology is not as systematic.

The predominant focus of all this work has been on epistemological issues - how the child comes to know as an adult does, and it has failed to provide a broad description of the common ideas that children have about the scientific phenomena addressed within a primary science education. The latter is now of interest as science has been a rapidly growing component of the curriculum which, as a consequence of the National Curriculum, has now become compulsory for all children from age 5-16.

1.2. The Growth of Primary Science

The growth of a broad education about science within primary schools is a relatively recent phenomena. Prior to 1960, science education, if it occurred at all, was commonly restricted to 'nature studies'. However, during this decade, the growing impact of science on society lead to a recognition that science is an important dimension of our cultural experience and enabled the ASE (1961) to argue that - "Science should play a vital part in general education" and to recommend that "*All* school pupils should study science in *all* stages of their school life." This policy statement went further in defining the form that such an education in science should take for primary children when it stated:-

> "In the primary stage we are concerned more with the development of an enquiring attitude of mind than with the learning of facts and the appropriate approach is through discovery and 'finding out activities'. .....It is not desirable to prescribe a standard syllabus for the primary stage. The teacher must be free to follow whatever promising lines of enquiry seem to be developing."
>
> ASE (1961), p 3.

Similarly, in the American scheme for elementary science (American Association for the Advancement of Science, 1963), we find the view expressed that -

> "Science is best taught as a procedure of enquiry. Just as reading is a fundamental instrument for exploring whatever may be written, so science is a fundamental instrument for exploring whatever may be tested by observation and experiment. Science is more than a body of facts, a collection of principles, and a set of machines for measurement; it is a structured and directed way of asking and answering questions."
>
> (AAAS, 1963), p. 3.

Such a view which placed an emphasis on process rather than content for young children's science education focused on the epistemological question - 'How we know' rather than the ontological question - 'What we know'. Primary science was presented as a way of learning, elegantly described by one child as

> "...like being in a small plane flying over a vast open landscape like a desert. You could land anywhere to have a look around and explore for a while. There was a sense in which it didn't seem to matter too much *where* you had landed, because it was the exploring that was important, not so much what you found.'
>
> (Claxton, 1991), p 25.

In the UK, this emphasis on process rather than content, that is the procedures by which data are collected and transformed to extract and formulate relationships made primary science distinctive from secondary science which saw its central concern as the transmission of a body of knowledge, rather than a way of knowing.

However, whilst the stress on process was a mechanism by which primary science defended itself from the invasion of the ethos of secondary science, it is now possible to see that the dichotomy between the two was, as Millar and Driver (1987) have argued, a false dichotomy.

1.3. Primary Science - A New Approach

Concern that there might be an imbalance between concepts and processes had already begun to emerge as an issue for consideration within primary science (Harlen, 1978, Kerr & Engel, 1980; DES, 1983) and in New Zealand, an attempt had been made (Osborne & Biddulph, 1985) to develop an 'interactive model of teaching' which moved away from the dominance of process approaches. Thus, in a paper written in 1986 (but not published till 1993), Black & Harlen (1993) discussed the interplay between process and concepts in terms of two aspects: their categorisation, that is the process by which a particular concept is selected or rejected for use, and their transformation - the use of the concept to make predictions and to invent procedures for solving new problems, processes which do not make an artificial distinction between content and process.

Black and Harlen (1993) then argue that since research has shown that children hold informal concepts and that these are "effective and robust, the design of teaching has to use some strategy for changing concepts" if science education in the primary school is to be effective. They suggest that a possible strategy would involve "the critical use of process skills" and that "it may be essential to understand children's ideas before one can start" as a basis on which to build.

Black and Harlen do not argue that their proposal constitutes an elaborated theory, but that their ideas are a contribution to the development of theory. Conceptual change, they propose, will be a question of blocking a categorisation of one concept and opening a new categorisation so that one concept will be curtailed whilst another is augmented. The emphasis on the need to ascertain what the child already knows is in essence a direct reference to the view of learning promoted by (Ausubel, 1968) and the constructivist view of learning (Osborne & Whittrock, 1983; Driver, 1983; Driver & Oldham, 1985).

For the selection of concepts within science education, Black and Harlen elaborate four criteria which relate to what is known about children's ability to learn with understanding. These are that:-

i. The concepts should help children's understanding of everyday events and of the world around them and should be applicable to their experience;

ii. Children should be able to take part in the generation and testing of concepts through the use of process skills;

iii. Concepts should be at a level which children can learn with understanding, taking into account their limited experience and maturity;

iv. The concepts should provide a foundation for later learning in science.

These ideas were to lay the foundation for the SPACE (Science Process and Concept Exploration) research project which was later to become a curriculum development project. Part of the justification for this research lies in Harlen's (1985) comment that-

> "it has to be acknowledged that, since primary science is relatively young, there is no great volume of research and tradition of scholarship in this areas as there is for secondary science education." (Harlen, 1985), p. 1

The Primary SPACE project set out to make a major contribution to a knowledge of children's understanding of science and its development. Essentially it was a classroom-based research whose two fundamental aims were to establish

- the ideas which primary school children have in particular concept areas;

- the possibility of children modifying their ideas as the result of relevant experiences.

The research was funded by the Nuffield Foundation and undertaken jointly by the Centre for Educational Studies, King's College London and the Centre for Research in Primary Science and Technology, University of Liverpool. This thesis is a report and analysis of the data that was collected by King's College. The data was collected by a team of 4 researchers, analysed written up for publication by the author with the assistance of Professor P. Black who acted in a supervisory capacity. A full statement of the extent of the work undertaken by different individuals can be found in Appendix 1.

Chapter 2 of this thesis is an extensive introduction to the background and issues raised by this research. As such it will explore more fully the growth of primary science, the relationship of content and process, the development of constructivist approaches to the learning of science and the implications of a Piagetian account of children's capacity to manipulate concepts and their symbolic representations. All of these issues have influenced the research questionswhich form the conclusion of this chapter and the basis of this work.

Chapter 3 will provide a general view of the methodology whilst chapter 4, 5, 6 and 7 will present an edited version of the published research reports reviewing, analysing and discussing the data collected for young children's understanding and its development in the domains of light (Osborne, Black, Smith, & Meadows, 1990); electricity (Osborne, Black, Smith, & Meadows, 1991); processes of life (Osborne, Wadsworth & Black, 1992) and the Earth in Space[1] (Osborne, Black, Wadsworth & Meadows, 1993).

Chapter 8 will discuss the results of the work and focus on three aspects: firstly it will review and summarise what evidence there now exists for the success of an approach to teaching and learning based on the approach outlined in Chapter 2. Secondly it will examine the nature of children's explanations and aim to explore to what extent the data support or deny four current perspectives or accounts of children's thinking. These are the 'constructivist' view of learning (Driver, 1989b), a developmental perspective (Piaget, 1950), the view that children's reasoning is based on intuition and a commonsense ontology (diSessa, 1983; Bliss, Ogborn, & Whitelock, 1989;

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1 This term is commonly used to refer to astronomy and simple explanations of the seasons and diurnal changes.

Bliss & Ogborn, 1993; Stavy & Tirosh, 1993) and knowledge as a social construction which emphasises the role of language and access to language (Polyani, 1958; Solomon, 1983). It will argue that the latter is an important aspect of the means by which the child constructs understanding and an important foci for future research.

Finally, it will aim to critically reflect on and discuss the issues raised by the theoretical models underpinning this research and a constructivist approach to the learning and teaching of science. As such it will aim to review the weaknesses and strengths of such a curriculum and pedagogy with the intention of extracting lessons for future research and development.

2. *Background and context to the SPACE project*

2.1. Introduction

This chapter provides the research context and background for this thesis. It begins by examining the growth and development of primary science, from its initial inception as nature studies in elementary schools in the mid-19th century to its present format. A particular focus is the transition that occurred in the nature of primary science in the 1960s under the influence of several major curriculum projects. Their general impact was to broaden the scope of the science taught and to give pre-eminence to learning and exploring the processes of science, as opposed to content. The failure of these projects to reach the majority of primary schools led to a re-examination of this emphasis. It will be argued here that the division between content and process is a false dichotomy and that for the purpose of learning science, processes are subservient to content.

A major influence on primary science, prior to this research and the National Curriculum, has been the work of Jean Piaget, particularly in the choice of content to be taught. This work summarises the contribution of Piaget and discusses the criticisms of his epistemological theory to demonstrate that Piaget's domain-general considerations, which argue for unitary cognitive structures, are not as important at this age, as issues of a domain-specific nature defined by particular contexts and tasks. This paradigmatic research, which is commonly known as the 'alternative conceptions movement' and its theoretical underpinnings, are the framework for this research. Its implications are discussed here to show how it has led to the formulation of the research questions which form the basis of this research and the conclusion of this chapter.

2.2. The growth and development of Primary Science.

Towards the end of the century, it is possible to see the growth and development of primary science in the UK in three phases. For the first hundred years, the study of science in primary schools was essentially restricted to nature study and its inception in this form has been well-documented by Layton (1973). He shows how in 1853, Lyon Playfair, the then senior civil servant in the Department of Science and Art, argued that 'the sciences of observation such as zoology, botany and physiology, are more suitable to the children of primary schools.' Such views came to prevail and over a hundred years later, Jean Conran writing a personal view of primary science from 1950-82 gives a picture of primary science at the beginning of her career which is still remarkably consistent with this view.

> "We started the year with a 'Seaside Room'. Ready beforehand were displays of shells, pebbles, and sand; aquaria with live crabs and sea anenomes; seaweeds; boxes and tables for collections made during the summer holidays; drawing materials, paper for labelling and selection of named specimens, reference books and pictures. We then followed the seasons with an ever changing set of exhibits, a growing family of resident plants and animals, and a flow of temporary visitors brought in by the children. They marvelled at the unfamiliar and became confident in handling and caring for the familiar......Animals and plants were kept at home and books were purchased or borrowed from the library. Research was undertaken into cats and dogs. Diaries were kept. Expeditions to parks, museums and zoos were made on Saturdays and the children brought along parents, siblings and friends. "
>
> (Conran, 1983), p 18.

However, the 1960s were a time of change and a number of factors contributed to this shift. Culturally the decade itself was a time of expansion, development and optimism for the future, much of it generated by the technological advances made by science and technology. Most importantly, it was a time of re-evaluation of the then current practice in science education. Dissatisfaction that the restricted scope of nature studies only represented a very narrow dimension of the science perceived and used by society was being expressed. These sentiments were officially articulated by the Ministry of Education (1961). At the same time, the ASE[1] established a committee to consider the role and nature of primary science. In their report, they rejected the notion that science in primary schools should be a simplified version of secondary science. Instead they stressed the importance of seeing science as a way of working, and argued that 'at this level, we are concerned more with the developing of an enquiring attitude of mind than with the learning of facts '(ASE, 1963).

In this climate, two groups were able to find funding for major curriculum development projects, the Oxford Primary Science Project (Redman, Brereton, & Boyers, 1969) and Nuffield Junior Science (Wastnedge et al, 1967). The two differed significantly in their approach - the former attempting to "discover which *scientific concepts* [2] children can form, and to identify the experiences which are fruitful in helping children to form concepts" whilst Wastnedge et al sought to place the "greater emphasis, however on the so-called 'processes' - observing, pattern-seeking,

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1 Known then as the Science Masters Association

2 Emphasis added.

hypothesizing and planning experiments." Also paramount to this project was the opportunity for children to have first-hand, concrete experiences and to initiate work from children's own questions, for this mode of working was considered to maximise motivation. For Nuffield Junior Science, the issue of content was essentially secondary as it 'would be taken care of by choosing a suitable range of starting points and by a school staff planning topics to avoid duplication.' Further support for this approach was provided by the Plowden report (Central Advisory Council for Education (England), 1967). Heavily influenced by the findings of Piaget it argued that 'children can only learn efficiently from concrete situations' and that 'Piaget's observations support the belief that children have a natural urge to explore and discover.' Primary science education should therefore be a process of 'learning by discovery'. This child-centred view of education emerged as the predominant educational ideology of the time and may account for the failure of the Oxford Science project to reach a wider audience.

In contrast, Wastnedge (1983) was able to convince the School Council in 1967 to fund a five-year continuation project known as Science 5-13. This complex curriculum scheme was defined by a set of 150 objectives which were each related firstly to one of three Piagetian stages of development in children:- Stage 1 - transition from pre-concrete to concrete; stage 2 - concrete operational, and stage 3 - the transition to early formal thinking. Clearly this project was heavily influenced by the writings of Piaget, but more importantly, the objectives were also tied to one of eight general aims for science teaching which were heavily weighted towards the processes of science -

- observing, exploring and ordering observations;
- developing basic concepts and logical thinking,
- posing questions
- devising experiments or investigations to answer such questions;
- acquiring knowledge and learning skills;
- communicating;
- interpreting findings critically;
- appreciating patterns and relationships.

This was an ambitious project whose

> "main thrust ....was to offer teachers guidance at a reflective level in order that they might, by 'working with objectives in mind', gain deeper understanding of what was seen to be desirable for children of differing stages of development to achieve

> through their work in science, and through such understanding gain confidence to cope better with the practicalities of teaching."
>
> (Parker-Jelly, 1983), p149

Parker-Jelly claims that the influence of the project can be detected in a range of policy statements and curriculum projects which were to emerge in the following decade such as Harlen's (1977) *Match and Mismatch,* Richard's (1980) Learning through Science Project, the Starting Science Materials (Derbyshire LEA, 1976) and the Sciencewise Series (Parker & Ward, 1978). An examination of these projects would support this assertion.

Thus, it is possible to see the development of primary science over these two decades as being strongly influenced by two strong themes - Piagetian developmental psychology, and an overarching concern with science as a process of enquiry and investigation where considerations of appropriate content were essentially secondary. Even then, science was not accorded a high priority as Ashton's (1975) study, collected between 1969-72, showed. He asked 1513 teachers to rate seventy two aims of primary education. That the child should 'know some basic scientific procedures and concepts' was rated 62nd.

The emphasis on process was still present in the APU Survey (DES, 1981) conducted six years later. When teachers were asked to rate twelve goals of science based activities, the top three were 'A questioning attitude towards their surroundings' (95%); 'Ability to observe carefully' (92%), and 'Enjoyment of science based work' (78%). The percentage prioritising content based goals such as 'Knowledge of the natural and physical world' and 'Understanding of basic science concepts' were significantly less at 62% and 28% respectively. Moreover, the authors makes the point that those goals which were highly ranked are not specifically related to science, whereas process objectives that are, such as 'the ability to plan experiments' (11%) and the 'recognition of patterns in the observation of data' (38%), were not rated highly. The authors are forced to conclude that 'the essential nature of primary science as a process of enquiry has not been carried forward to any degree in the work of the pupils.'

2.3. Criticisms and failures of Primary Science

Critiques of the emphasis on process had been articulated, even from its inception. For instance, Myron-Atkin (1968) argued that "a basic flaw in the process approach is that apparent assumption that science is a sort of commonsensical activity and that the 'appropriate skills' are the primary ingredients in doing productive work." And, in a forerunner of the constructivist perspective, continued by stating that 'there seems to be no explicit recognition of the powerful conceptual frames of reference within which scientists and children operate and to which they are firmly bound." However, serious concerns with the approach developed for primary science did not really emerge until the late seventies.

These concerns were essentially threefold. Firstly the low uptake and poor dissemination of primary science was problematic. Secondly, more voices began to question the overemphasis on the processes of science, and finally, several notable critiques of Piagetian psychology, the theoretical basis for the major schemes, were emerging.

In 1978, The Schools Council published a survey of the impact and uptake of their own funded projects (Steadman, 1978). In a large sample, 740 schools were visited and questionnaires obtained from 1146 more. The data from this survey showed that Science 5-13 was known to only 36% of these schools, 30% of the headteachers claiming the books were used as against 22% of the teachers. A similar picture emerged of Nuffield Junior Science from a random sample of 279 schools. The materials were known to only 18% and 13% were using the materials, according to the headteachers, but only 7% of the teachers said they were doing so. These data probably portray a bleaker picture of the project's significance than is the case. For, as Parker-Jelly (1983) points out, the scheme was a publishing success with over a million copies sold; the materials were extensively used on teacher-training courses; and they were influential with other projects.

Whilst, there is clearly some uncertainty about the implications of these data, the HMI survey (DES, 1978) published the same year gave another objective picture of primary science that was not encouraging, a flavour of which can be found in the following paragraphs.

> ' 5.69. ....Although some science was attempted in the majority of the classes, the work was developed seriously in only just over one class in ten, either as a study in its own right, or in relation to other topics being studied.'

> ' 5.78.........In only a very small minority of classes were activities requiring careful observation and accurate recording developed beyond a superficial level and in less than one class in thirty was there any evidence of investigations which had been initiated as a result of questions asked by the children.'

> '5.79. In those classes where efforts were made to introduce children to science as both a body of organised knowledge and an experimental process the emphasis tended to be placed on work relating to plants and animals.'

This HMI Survey also showed that twice as many schools had schemes of work for mathematics and language as they had for science and the inspectors were forced to conclude that 'the progress of science teaching in primary schools has been disappointing; the ideas and materials produced by the curriculum development projects have had little impact in the majority of schools.'

Consequently, the HMI survey of 1978 caused many workers in the field of primary science to pause and re-evaluate their position, particularly the relationship between content and process.

2.4. Process in Primary Science reconsidered

Black (1980) initiated the debate in an article entitled 'Why hasn't it worked?' arguing that 'it was not now obvious that the best route for developing an understanding of science was to concentrate exclusively on the process skills of a concept-free science.' More fundamentally, Kerr and Engel (1980) questioned 'Can Science be taught in Primary schools?' They identified three factors contributing to the poor state of affairs in primary science - the poor science background of teachers which undermined their confidence; the failure of headteachers to recognise the potential contribution of science to the curriculum; and the inadequate provision of simple apparatus and materials. But their main conclusion was that it was unreasonable to leave the content of science to teachers who lacked the background to make appropriate choices and that, 'if science *should* continue to be taught in primary schools, an adjustment of policy is desirable.'

Slowly, the argument for a common syllabus and more determination of content was articulated. At a national level, the impetus for greater specification within the education service had been given by James Callaghan's speech at Ruskin College in 1976 which argued for agreed policies on the school curriculum. Within primary science, the case was made in a series of articles (Booth, 1971; Booth, 1978; Harlen, 1978; Black, 1980; Kerr & Engel, 1980). Typical was Harlen who argued for a balance - 'a set of ideas, generalisations and facts that children should encounter' and sketched out a list of content ideas which now look remarkably like some of the statements of attainment in the current National Curriculum (DES, 1991). Thus Richards (1983) was able to conclude:

> "In recent years, a consensus appears to be developing.....On this view, processes, generalizations and concepts are all seen as important criteria for the selection of activities. Within this overall stance, process criteria are still seen as important but not nearly to the same degree as in the orthodoxy of ten years ago. "
>
> (Richards, 1983), p 6

Moreover, Richards also makes a case for curriculum continuity in three forms: continuity within any one year, continuity from year to year and continuity from phase to phase. This can only be achieved through 'common agreement as to the basic structure of the subject.' Possibly, Richards was only reflecting the underlying thinking of documents produced by the DES, *The School Curriculum* (DES/Welsh Office, 1981) *Science in the Primary School* (DES, 1983) and by the Schools Council, *The Practical Curriculum* (Schools Council, 1981), which sought to set out a broad structure for the curriculum at national level. This was given explicit articulation in the White paper, *Better Schools* (DES, 1985), which resulted in a set of proposals for a National Curriculum (DES, 1987) and ultimately the production of a set of statutory guidelines (DES, 1989). Thus these socio-political initiatives made a primary science education a compulsory experience for all children and brought to the fore the issue of determining appropriate content for the primary curriculum - *a fundamental question which this research sought to inform.*

The choice of content in previous projects had been extensively influenced by the work of Piaget. However, criticisms of Piaget's work, and its interpretation by developmentalists working in science education (Shayer & Adey, 1981; Lawson & Wollman, 1976), were beginning to emerge.

Furthermore, new research which reported a different dimension to pupil's difficulties with learning science provided another paradigm for approaching the teaching and learning of science. This body of research demonstrated that children held 'alternative conceptions', which others called misconceptions or 'alternative frameworks' (Driver & Easley, 1978) which persisted, despite instruction. These beliefs or ideas were used by children to make sense of new information. Thus the process of teaching required children's existing ideas to be challenged and altered, rather than developed anew, and children had to construct new knowledge for themselves. This particular model of learning has acquired the term 'constructivism' and it is the predominant influence on this research.

Before exploring the issues raised by such a theoretical position and its associated methodology, it is important to explore here the epistemological problems raised by the 'process' approach commonly adopted in primary science curriculum development, as only an improved comprehension of the nature of the science that we require children to learn and understand will enable better choices to be made in the development of an effective pedagogy, and avoid the overemphasis of one dimension at the expense of another.

2.5 A Critique of process approach for the teaching and learning of science.

Ogborn (1988) has argued that education in science attempts to answer five questions:-

- What do we know? - the ontological question.
- How do we know? -the epistemological question.
- Why does it happen? - the causal question.
- What we can do with our knowledge? - the technological question.
- How we can communicate these ideas? - the communicative question.

The 'process' approach to the teaching of science concerns itself fundamentally with the second question, and possibly the final question but gives scant attention to the other questions which are fundamental to scientific activity. From a different perspective, Hodson (1990) distinguishes three dimensions to an education in science - learning science, doing science and learning about science. Clearly the first two are identifiable as the content and processes of science but the third which he characterises as an awareness of the methods and history of science is novel. From either of these positions, the 'process' approach to the teaching of science would appear essentially one dimensional, addressing only a subset of the reasons for learning science.

Some authors (White, 1988; Screen, 1986) have attempted to argue that the choice of content can not be considered important as the consensus of what constitutes valid knowledge for the science curriculum is ever changing, illustrating their argument with references to curriculum material e.g. Searle's bar, Atwood machines and ergs which they portray as arcane. This argument is then used as a justification for a process approach on the basis that the methods of science are unchanging and independent of content.

However, two principal objections can be raised in reply. Firstly, while aspects of the curriculum may come and go, i.e. geometrical optics, the thermionic valve, Atwoods machine, there remains a core which is unchanging. For, as Weinberg (1968) has remarked, 'if science is all that ephemeral, if Newton's second law must indeed be classed as a temporary codex, it is somewhat surprising that science has been as useful as it has in human undertakings.' Thus in a Lakatosian sense, the core concepts and heuristics of science, and science education, such as classification, the periodic table and Newtonian dynamics remain relatively unchanging.

Secondly, the case has been convincingly made by Millar and Driver (1987) that there is no agreement about the method or processes of science, and the argument that there is any specifiable methodology cannot be sustained. Their objections, as follows, are several:

- Since there is no agreement amongst philosophers of science about the nature and methods of science, the lack of a common understanding would imply that there is an inadequate rationale to justify such an emphasis on a 'process' approach.

- What children learn from a phenomenondepends not only on the attributes they abstract from the situation, but on the constructions that they bring to it. Therefore, a simple empirical description of science as a process of inductive generalisation based in observation is simply inadequate because there exists a dialectic *between* theory and experience rather than a one-way derivation of theory *from* experience.

- 'Process' based approaches are based on the unproven notion that generalised content-independent procedures can be taught and applied by learners in new contexts. However, the evidence is that most of our reasoning is tied to particular contexts. Furthermore, the idea of teaching a 'process' implies some notion of what constitutes progression on a 'process skill' such as classifying. But as Millar & Driver (1987) argue, 'what is 'easy' classifying as opposed to difficult 'classifying?'

They point out that all the works of philosophers reinforce the same conclusion. Furthermore they argue that the so-called 'processes of science' are the characteristics of logical thought in general. The subtle, but important distinction, that needs to be drawn is that science lessons should not attempt to develop simply observation, classification, hypothesising but *scientific* observation, *scientific* classification and *scientific* hypothesing. The latter techniques require children to learn the elements of a complex situation which are scientifically worth observing, to learn the observations which are relevant to scientific classification and to conceptualise the task in a manner which reflects a scientific approach. Thus for Millar and Driver, ' what children learn from an interaction with phenomena......depends not only on what they *abstract* from the situation but also on the mental constructs they bring *to* it.'

Moreover, they are implicitly making the case that science has its own characteristic body of semantic knowledge (knowledge that..) which is associated with a characteristic set of procedural knowledge (knowledge how...) which are specific to the domain. The significance of this point will be more apparent when the approach to learning of the constructivists is discussed.

Possibly some of the overemphasis on the 'processes of science' can be attributed to Gagné (1965) who argued that scientific concepts and principles are obtained only through the operation of a set of scientific processes such as observing, classifying, formulating hypotheses etc. His thesis was that these processes and skills are used by all scientists and can be learnt by students across content domains. However, the contention here is that processes are only a component of science and not *pedagogic ends in themselves*. The fundamental reason for teaching scientific processes is that it introduces the pupil to a range of standard methodological procedures which enable the scientist to justify his or her knowledge claims. The consequence of confusion and lack of clarity about this important distinction has lead many primary science projects, and some secondary science schemes, to provide a science education which gives a limited perspective on science for children, answering only a restricted subset of Ogborn's questions.

Consequently, the only tenable position in approaching the design of the science education curriculum is one which sees content and process as interdependent and inseparable. Children's ideas and concepts are what they use to make sense of their observations. But, by the selection of appropriate activities and by the application of *scientific* processes, their existing ideas can be augmented and challenged and new ideas developed. This view reflects the basic focus of this research which sees processes as subsidiary to the development of a deeper understanding of the concepts, applications and purposes of science. A knowledge of the concepts and ideas of science is the essence of scientific literacy, enabling the individual to communicate with scientists and assess the value and importance of their work to society and their own lives. Thus the explicit values that underpin this research concur with those expressed by Miller & Driver (1987) who see science as a body of knowledge 'characterised by its concepts and purposes, not by its methods.'

However, such a position engenders further questions. Specifically these can be seen as decisions about content and pedagogy. Which of the ideas and concepts of science can, and should be introduced to children between the ages of 5 and 11? Furthermore, once an agreement on this issue has been achieved - through what process and activities should such material be delivered? The two major influences on the choices to be made in formulating a response to these problems are the work of Jean Piaget and the large body of work that has been conducted into children's alternative conceptions. Both have important implications for this research and will now be considered.

2.6. The work of Jean Piaget and its implications

At the heart of Piaget's work are two essential principles - that the child goes through a process of cognitive development, and that this development is characterised by stages which are qualitatively different from each other, and from adult thinking which represents the endpoint of this process of maturation. Piaget's ideas and work were elaborated in a number of books but possibly the most influential, in terms of the dissemination of his ideas, were *The Origins of Intelligence in Children* (1953), *The Child's Construction of Reality* (Piaget, 1954) and (with Inhelder), *The Growth of Logical Thinking* (1958).

In the growth and development of the child's mental capabilities, the first important achievement the young child (12-18 months) makes is the ability to find a favourite toy which has been hidden. Piaget argues that this achievement is a substantial development as he or she has begun the process of mentally representing objects, and therefore, the young child can remember an object exists, even though it cannot be perceived. The ability to formulate such representations is essential to the process of abstraction and generalisation, as mental images are the building bricks of abstract thought.

The next stage of development is termed the period of pre-operational thought and lasts until approximately age 5 to 7. The exact age varies from child to child and is also the subject of some disagreement (Sutherland, 1992). In this period, the process of symbolic representation develops. This stage is probably the least well-researched but is characterised by thinking which is egocentric, and which is intuitive and animistic in nature. The latter is the tendency to endow inanimate objects with human qualities. During this phase, the child's language is developing and the increasing ability to represent experience symbolically enables the child to internalise mentally their own experiences. Increasing facility with this process also enables the child to begin decentering and interpreting events from other aspects, instead of focusing exclusively on one.

After this stage the child makes a qualitative transition to the stage of concrete operations. The child is now able to mentally manipulate representations of objects which are physically present. The child can also abstract aspects of the situation and will conserve quantities in transformations. So when water is poured from a tall, thin vessel to a low, wide one, the concrete thinker will correctly be able to identify that quantity of water is the same in both containers, an operation on which a pre-operational thinker would fail. The child's thinking is characterised by the ability to compensate - the vessel may be lower but it is wider. Other mental operations also feature in a child's thinking at this stage; seriation which is the ability to sort a string of objects according to a single criteria and transitivity which is the ability to follow correctly interpret logical statements of the form 'if A is bigger than B, and B is bigger than C, then A must be bigger than C.'

The final stage is the achievement of formal operations. In this stage, the child is capable of reasoning symbolically and independently of any concrete props. Now the child is able to conceive of imagined entities such as particles or electric currents and perform hypothetico-deductive operations and analyse and evaluate the implications of their own reasoning. Shayer and Adey (1981) describe this as the ability to indirectly interpret 'reality by deductive comparison from a postulated system with its own rules.' This is a sharp contrast to the inductive reasoning which characterises concrete thinking which is limited to generalisations from reality and personal experiences.

Piaget was not fundamentally concerned with developmental psychology but with the elaboration of a theory of knowledge and cognition in children. He himself described himself as an epistemologist, not a psychologist, but his ideas have been widely adopted by educationalists. At the core of Piaget's ideas are three processes which lead to cognitive development and maturation of the central nervous system. The initial consequence of any interaction by the child with its environment is an attempt to *assimilate* this experience by the use of familiar symbolic representations and mental operations. Thus assimilation involves transforming experience with the mind. If the child cannot assimilate this new information, a process of *equilibration* occurs which results in the *accommodation* of the new experience to the child's existing mental schema. Therefore accommodation leads to an adjustment of the mind and its cognitive structures and is an essential process for adapting to the environment. For as Flavell points out in his introduction to Piaget's work-

> 'Reality is not infinitely malleable...and the essence of accommodation is precisely this process of adapting oneself to the variagated requirements or demands which the world imposes on one. '
>
> (Flavell, 1963), p 48.

Piaget saw the development of such cognitive structures, which he termed schemas, as tightly bound to a class of action sequences whose development and elaboration came from a repetitive process of assimilation, equilibration and accommodation through acting on the world. Since schemas are closely related to actions, they are not equivalent to the notion of a concept but they do share with the latter important structural connotations which are not indigenous to the concrete content of the child's actions. Hence they represent the beginnings of the child's attempt to represent the world mentally to themselves and, in the sense that individuals do construct mental representations of the world, Piaget can be considered a constructivist (Bliss, 1993). A process of repetition, generalisation by extending the domain of application, and differentiation of the global schema into several new schema then leads to mental structures which enable operational thought which is independent of action i.e, formal operational thinking and mature adult thought.

Piaget's theories have considerable implications for science education as science makes extensive use of logico-mathematical operations and symbolic propositions for hypthetico-deductive thought. From this perspective, the ability to think in such a manner was only possible for individuals who achieved the cognitive structure of formal operations. In *The Growth of Logical Thinking* (1958), Inhelder and Piaget argue that formal operations are a generalised processing capacity which is based on a symbolic calculus of 10 schemas which fall into three groups: -the facility to *handle variables* by controlling and excluding irrelevant variables and to classify and categorise data; the ability to comprehend and manipulate *relationships between variables* in the form of ratio and proportionality, to compensate between variables, to see correlations and to analyse probabalistic relationships; and finally, the ability to construct and use *formal models* and logical reasoning. Hence if these processes are fundamental to comprehending scientific concepts, Piaget's work has considerable implications for the structuring of the content of the science curriculum. And, as has been noted, did have a strong influence on the development of primary science it curricula in the 1960s.

In science education, the main development of Piaget's work has been undertaken by Shayer and Adey (1981) who have sought to develop two sorts of measuring instruments - a) an instrument for measuring the development of pupils' mental schemas, and b) an instrument for determining the cognitive complexity of curriculum material. The former task they have undertaken through the development of a set of 'Science Reasoning Tasks', the validity of which has been extensively tested (Shayer, Adey, & Wylam, 1980). From the application of these tests to a sample of 14 000 students, they were able to construct a representative picture of the normative cognitive development of the population. (Fig 2.1).

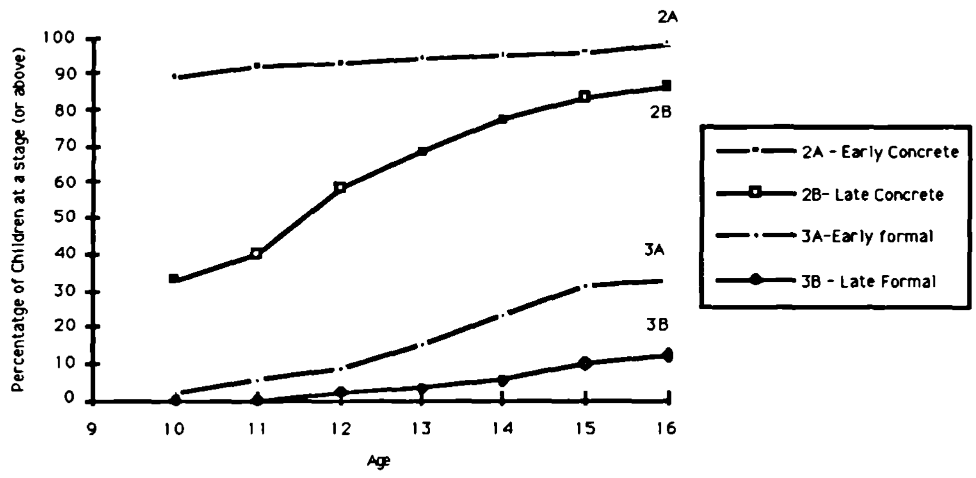

Fig 2.1: Proportion of Children at different Piagetian stages in a representative sample of the British child population

The second instrument devised was a pair of Curriculum Analysis Taxonomies (CATs) which respectively described the psychological characteristics of children's thinking and the intellectual schemas specific to different types of science activity. Given 'well-specified' curriculum objectives, the authors claim that these taxonomies enable the cognitive demand of any science syllabus to be determined. Convincing evidence for their validity is provided in the form of an experiment which shows a high level of agreement between assessors estimates of the level of difficulty of curriculum material using the CATs, and actual pupil performance. A recent analysis of the cognitive demands of the National Curriculum by Shayer (1991) shows that all the work at level 1 and 2 of the National Curriculum requires only early or mid-concrete operations. However, by level 5, which is supposed to be indicative of the achievements of the more able 11 year old child (Black, 1987), approximately 50% of the statements of attainment require early formal thinking.

Thus, the implications of this developmental approach for the choice of curriculum content for primary science and this research are self-evident - any content should concentrate on that which requires only concrete operations to manipulate the variables, conserve quantities, classify materials or organisms, perform seriations etc.

However, there a number of criticisms of the developmentalists' account of learning, and in addition, a body of research work that argues that the most important factor affecting a child's capacity to learn is not their generalised cognitive capabilities, but their knowledge and ideas that they already hold about the world. It is the contention the of this research, that whilst the Piagetian account is important in describing an aspect of learning, there are a number of criticisms that call into question the scope of its applicability, and of greater import to primary science is the latter research, which has acquired the generic term of 'alternative conceptions' and whose theoretical position is described as 'constructivist'.

2.7. Critiques of Piaget's Work

> "Central to the position of the cognitive developmentalists is a belief in some kind of general processing mechanism of the mind which controls all comprehension. All intellectual activity, in whatever subject domain, is monitored by this general processor. Furthermore, as the term 'cognitive development' implies, it is supposed that the effectiveness and power of the general processor develops from conception to maturity under the influence of genetic programming, maturation and experience."
>
> (Adey & Shayer, 1994), p 6

This statement by Adey and Shayer is a concise summary of the 'hard core' (Lakatos & Musgrave, 1974) or the 'negative heuristic' of the developmentalist approach to the teaching and learning of science. Therefore their approach is to ask what kind of experiences will aid and assist the development of this central processor so that it can assimilate concepts and ideas which are inherently more demanding. In essence, the unitary nature of the developmental structure in the child has great appeal as its coherence simplifies many fundamental educational problems. What evidence is there to suggest therefore that this perspective is an over-simplification and that the issue of children's learning is only described by at least a more complex picture, if not a different one altogether?

a) Decalage.

The first problem encountered with the concept of the level of cognitive functioning being determined by the capabilities of some central processor is the asynchrony of achievement of concrete/formal operations in different contexts. This has become known as *decalage* (Brown & Desforges, 1979; Sutherland, 1989). Such results would suggest that the ability to reason formally using logico-mathematical operations is context-dependent and not universal across domains. This result challenges the basic ideas advanced by Piaget. However, there are two possible explanations for this result which would leave Piaget's theoretical position unharmed.

Firstly Adey and Shayer (1994) argue, using data from research by Longeot (1978) and some of their own, that there are nodes of development in a child's cognitive facilities. So while some children may succeed on a conservation task first and others on seriation or classification, progress to the next stage is dependent on achieving success with all these schema. Secondly as Monk (1990) has argued, the developmental stage of the individual represents a maximal limit to their capabilities. In an unfamiliar sphere, formal thinkers who have failed to internalise the essential concrete aspects of the domain, will only be capable of concrete thinking as they have not accommodated the variables necessary for operational thinking at a formal level.

Such arguments, in Lakatosian terms, do form a protective belt for Piagetian stage theory and hence, of themselves, do not offer a critique which renders developmental stage theory invalid.

b) Task Interpretation

Two more attacks have been mounted by Margaret Donaldson (1978), one more serious than the other. Donaldson's basic technique is to take standard Piagetian tasks, change the context or the language used in formulating or presenting the task to children, and then show that the children are much more capable of performing the required operation than shown by Piaget's data. Unfortunately, in some cases, Donaldson overworks the evidence. One of her core examples is the experiment done by Martin Hughes (1978) to explore children's capability to perceive a situation from another's point of view, a replication of an experiment performed by Piaget.

Piaget used a model mountain, on which were certain features such as a house, tree etc. A doll is placed at a variety of positions around the table and the child asked 'What will the doll see?' Children under the age of eight find this very difficult. The author's own experience of asking primary teachers on in-service courses to undertake a similar task and sketch what they will see from another perspective would also confirm this view. Although nearly all could manage the task, they commented that it was a hard task, not to be asked of children.

Piaget, therefore used his data to argue that young children were fundamentally egotistical and not capable of decentring. In Hughes' modification of this task, a table is bisected by two perpendicular screens (Fig 2.2). The child sits at one position and a policeman is visible to her left at A. A doll is placed at various positions around the table and the child then asked if the doll will be visible to the policeman.

Hughes found that nearly all children between 3.5 and 5 years were capable of this task and Donaldson uses this result to argue that these data convincingly demonstrate that young children are capable of much higher order thinking than Piaget claims. However, this claim cannot be taken seriously as Piaget's task is clearly much more demanding, requiring the subject to imagine being in another position and what the view would look like from the other's perspective. Hughes' task simply requires the ability to see if the line of sight is intersected by the partition which is much less cognitively demanding.

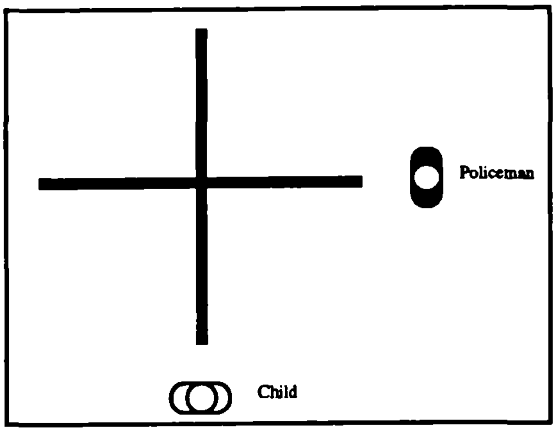

Fig 2.2: Experimental arrangement for replication of Piagetian experiment by Hughes

Donaldson's more substantive point is to question the interpretation that children make of the formal language used by Piaget. Starting with a well-argued attack on the Chomsykian notion of an internal language acquisition device, she then argues that there is a considerable difference between the adult meaning implicit to formal language, and the children's interpretation and use of that language. Her argument is based on two experiments. In one of these, children are shown 4 garages, joined in a row and containing a set of toy cars, consisting sometimes of 3 cars and sometimes of 5 cars. The children were then asked whether the following statement was true or not - 'All the cars are in the garages. All the garages have cars in them.' Surprisingly, these children held both statements to be false when there were three cars and both to be true when there were five. Donaldson and Lloyd (1974) argue that this result does not mean that the children have not understood the situation conceptually. Rather than focusing on the 1:1 correspondence, they have considered what *ought* to be there. All the garages ought to be full. Thus the child and the experimenter *mean different things by their words*. Therefore, true assessment of children's capabilities can only be approached when tasks are explained in language that is as helpful as possible for the child to comprehend the adult meaning. When this is done, as in some of her experiments, children appear to be much more capable than Piaget claimed. Donaldson reserves some of her fiercest criticisms for experiments in which Piaget gave children two incorrect answers to choose from, arguing that this is deliberately unhelpful.

However, ultimately it is difficult to see how her work falsifies the core notion of genetic epistemology - that there is a central processor whose operational capabilities change in fundamental ways from birth to adulthood. What it does achieve at least, is argue that Piaget's description is inaccurate or incomplete and that as Sutherland (1992) comments

> "..if we are going to research on children in a way that will allow them to show us their full potential, we must be aware of how children are representing, interpreting and construing their experiences. Overall it is language teachers and psychologists must concentrate on if they wish to help young children to progress."
>
> (Sutherland, 1992), p 72.

In summary, Donaldson's position would be one in which the acquisition of language leads to cognitive development *rather than* cognitive development leading to language development, the developmentalist position.

c) Failures of formal reasoning

Another major attack has been mounted by Wason and Johnson Laird (1972) with what has become known as 'the four card trick'. This required individuals to apply the rules of propositional calculus to determine the truth or falsity of a specific rule that applies to the combinations of vowels and letters on the card. Most individuals fail this test of formal reasoning and the authors argue that therefore any model of thinking based on symbolic logic, as Piaget's was, must be wrong. However, other research (Bond, 1980) has shown that when the problem is contextualised, performance improves and does correlate highly with Piagetian reasoning tasks (r=0.73). Adey and Shayer (1994) have also argued that Piaget never implied that reasoning could ever be disembedded from context and that failure to exhibit the highest forms of reasoning will often occur where subject's prior experience is inadequate 'to permit their highest level of processing.'

d) Other criticisms

A variety of other criticisms have been mounted by those that are concerned that there is no acceptable empirical evidence for the mechanisms that Piaget's theory proposes i.e. accommodation, equilibration (Bryant, 1972), and that there was a serious failure to consider individual differences (Brown & Desforges, 1979). A more fundamental attack has been made on the notion that the child's intelligence arises from its actions on the world by Butterworth (1994) who argues that the evidence that Thalidomide children, who lack some or all limbs, still pass through Piaget's sensori-motor stages, shows that the development of intelligence is dependent on the child's capacity to recognise objects in a visual space and that there is a strong social element to the development of their cognitive ability. As yet though, none of these attacks have ultimately been able to question the 'negative heuristic' of Piagetian psychology. Instead, a research programme initiated by Driver & Easley (1978) has emerged which has argued that it would be more profitable to study children's reasoning or 'alternative frameworks'. In their seminal paper, these authors raise three objections to the Piagetian account of stages. Firstly, that Piaget placed too much emphasis on his strong theoretical frame in the analysis of his data and ignored other possible interpretations; secondly, that he overlooked the extent to which knowledge about the world is the result of constructions for which there has to be social agreement, and finally that there was evidence that 'achievement in science depends to a greater extent upon specific abilities and prior experience than general levels of cognitive functioning'. Consequently they argued for the Popperian account of science where rival theories are constructed and tested, and against empiricism and discovery learning. Thus Piaget's work should be read for the insights it gave into children's thinking rather than the development of any underlying logical structures. But what evidence is there for this view and what theoretical position justifies their arguments?

2.8 The Constructivist View on Learning: Evidence and Theoretical basis.

During the mid-seventies, research work in science education began to emerge which pointed to a different interpretation of children's difficulties in learning science. Early contributions were made by Nussbaum and Novick (1976) who looked at children's conception of the Earth, Guesne (1978) who explored children's understanding of light, Driver and Easley (1978) who undertook a comprehensive review of the literature and Viennot (1979) who investigated the difficulties students encountered with mechanics. The important aspect of all this work was not that the children or students had no conception to explain causal mechanisms, but that they often had very distinctive 'misconceptions' for which they were able to articulate a clear epistemological justification. The strong features of this work are that the ideas are personal, that is they have been internalised as a result of the child's own phenomenological experiences, and that the ideas are stable and resistant to modification by teaching. Instead, students often choose to ignore counter-evidence (Gunstone & White, 1981) or construct 'auxiliary hypotheses' (Rowell & Dawson, 1983) to explain inconsistent evidence presented in the classroom.

In the past decade, the work has mushroomed so extensively that there now exist two bibliographies of research work in the field (Carmichael, 1990), (Pfundt & Duit, 1991) and Duit (1993) has described the growth of research papers in the field as exponential. A synthesis of much of the research and its implications can be found in the following works -*The Pupil as a Scientist?* (Driver, 1983), *Learning in Science*

(Osborne & Freyberg, 1985), *Children's Ideas in Science* (Driver, Guesne, & Tiberghien, 1985), *Learning Science* (White, 1988), *Making Sense of Science* (Driver, Squires, Rushworth, & Wood-Robinson, 1994) and *Children's Informal Ideas in Science* (Black & Lucas, 1993) and aspects of this research relevant to this work are discussed in each of the Chapters 4, 5, 6 and 7.

This research had phenomenal impact because it has forced a sea-change in the perception of children as atheoretical individuals, where the function of teaching and learning is to provide children with new concepts and ideas, to one where children have theories which must be *challenged and reconstructed anew.* Typical of the period, was Black's comment:

> "Research with children is now establishing in this area, as in many others, that they construct their own conceptual schemes to cope with the problem of understanding nature, and that these, like those of every scientist up to the sixteenth century, are a real barrier to scientific understanding."
>
> (Black, 1980), p32.

This empirical data was not explicable from a developmental perspective and seemed to undermine Piaget's findings as children's capabilities to understand science appeared to be tied to a specific context, rather than describable in terms of general cognitive competencies. Therefore researchers in the field were forced to draw on alternative theoreticians to explain their findings and turned to the work of Ausubel (1968) and Kelly (1955).

The basic concept of Ausubel's work was the notion of meaningful verbal learning. Working in the 1960s, at a time when behaviourism and discovery learning were the dominant ideologies in psychology, Ausubel argued, in a quotation that has now become the hallmark of those working the constructivist paradigm, that

> "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly." Ausubel (1968), pvii.

His essential point was that new knowledge and information are interpreted in terms of the framework of our existing ideas and concepts. A similar case has been made from a philosophical perspective by Hanson (1958) and Harré (1986). The latter argues that 'theory is a device for focussing our attention. Theory precedes fact....because a theory determines where in the multiplicity of natural phenomena, we should seek for *its*[3] evidence.'

Two consequences follow from this view of learning. Firstly, it becomes important for the teacher to assess and evaluate what a child's concepts are *prior to* instruction as this is the framework that the child will use to make sense of new ideas. Secondly, this information should be used by the teacher to present new concepts in a form that the child or student will be able to assimilate into their existing conceptual structure. A particular feature of the Ausubelian account of learning is the use of 'advance organisers'. Essentially, these are presented to the students prior to instruction as a general overview of the topic and attempt to provide a conceptual framework which show the interrelationships of the ideas. They are also valuable for the curriculum planner as an aid to identifying the concepts to be taught, their order and coherence. Wider use of such techniques would avoid much of secondary science education being an experience which Claxton (1991) has claimed is 'like being on a train in carriages that had blanked-out windows.....but because the windows were opaque you could not see the countryside in-between, so you did not know how the stations were linked or related to each other.'

The ideas of George Kelly (1955) have also been influential within the constructivist movement. Kelly saw learners as scientists in that they have ideas about the world which are regularly tested against reality. These theories and beliefs are refined as a result of daily experience and tuition and are used as a basis for hypothesising actions and outcomes. Kelly elaborated his theory into a personal-construct theory where concepts consisted of polar dichotomies. Individual conceptual frameworks could be ascertained by asking them to a) represent how they saw the dichotomies in a given domain, and b) make polar choices from these exemplars. From this a map of their personal constructs for a particular concept could be determined.

Kelly is important in providing further theoretical support for the essential constructivist position - that of a cognising individual who develops their ideas and theories by interaction with the environment. Kelly's ideas have influenced the growth and development of the school which have become known as 'personal constructivism' whose current advocate, Von Glaserfeld, (1987) holds a similar position arguing that :-

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3 Harré's emphasis

> "knowledge cannot and need not be 'true' in the sense that it *matches*[4] ontological reality, it only has to be 'viable' in the sense that it *fits* with the experiential constraints that limit the cognising organism's possibilities of acting and thinking."
>
> (Glaserfeld, 1989), p 162.

In essence, knowledge acquisition is not a passive process but an active one in which the individual's personal constructions are assembled and tested against their everyday experience and that of others.

Further elaboration of this theoretical position was undertaken by Osborne & Wittrock (1983; 1985) who argued for a generative model of learning. The key postulates of this model are that:-

- The learner's existing ideas influence what use is made of the senses and in this way the brain can be said to actively select material.
- Learner's existing ideas will influence what sensory input is attended to and what is ignored
- The input selected or attended to by the learner has no inherent meaning.
- The learner generates links between memory store and sensory input to actively construct new meaning.
- The learner uses the links generated and the sensory input to actively construct meaning.
- The learner may test the constructed meaning against other aspects of memory store and against meanings constructed as a result of other sensory input.
- The learner may subsume constructions into memory store.
- The need to generate links and actively construct, test out and subsume meanings requires individuals to accept a major responsibility for their own learning.

Thus, to develop the child's ideas and concepts, the learner must be active and exposed to a wide variety of sensory input from which they can construct *personal* meaning.

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4 Von Glaserfeld's emphasis

The appeal of any good theory is that it provides coherence and explanations for empirical evidence. In this case, the rapidly accumulating data showed that children had a range of 'misconceptions' (Helm, 1980) or 'alternative frameworks' (Driver & Easley, 1978) - that electric currents are used up in a circuit; that motion requires a continuous force to sustain it; that light travels further at night; that humans are not animals; that vision is an active process and many more. What constructivist theory and research was able to do was demonstrate that such ideas were simply children's commonsense interpretations of phenomena, their attempt to make sense of their life-experiences. Electric currents are used up because batteries do run out. Light clearly travels further at night because you can see a car's headlights much further away than you can in the day. Animals are things like cats, dogs and cows and humans are a separate and unrelated class of 'living thing'. And because individual children's experiences were diverse and various, research found that their ideas were too.

This research concurred with many teachers' classroom experience and appealed because it provided a theoretical interpretation and explanatory model of why so many children have difficulty with particular concepts in science. Whereas Piagetian stage theory explains why children may experience difficulty with science concepts because of the demands of the material itself, constructivism explains why the ideas *that children themselves hold* will cause them difficulty in interpreting the new material, a fundamentally different perspective.

Inevitably the question arises as to which of these two theories has greater utility in explaining the conceptual development that occurs in childhood. Constructivist research would indicate that children's reasoning is context-bound and formed from very specific experiences, and thus their thinking and cognitive capabilities are environmentally, and not genetically predetermined as developmental models would indicate. Donaldson (1978) makes a strong case for the importance of context in children's thinking. The child will naturally be disposed to see the situation in a certain way giving salience to some features rather than others and these will depend on their knowledge of language, their assessment of the intention of the experimenter and the manner in which the situation is represented to them. The notion that thought cannot be disembedded from content has recently received further support from cognitive scientists (Rogoff, Gauvain, & Ellis, 1984; Lave, 1988; Greeno, 1989) This school of thought , known as 'situated cognition', emphasises the importance of social interaction, the culture and environment and 'the dialectical structuring of the activity of persons acting in a setting.' (Lave, 1988). Lave and Rogoff base their arguments on a series of studies of individual task performance in context. For instance, Lave compared housewives' ability with de-contextualised mathematical operations with similar tasks necessary in a supermarket to compare unit prices (cost per unit weight) and make decisions about best-value buys. Their facility with these tasks in context were significantly superior and Lave (1988) is concerned that skills and knowledge acquired in formal school settings is not transferred to real-life situations. The work of these researchers clearly highlights the problem of transfer of learning from one context to another. More importantly for this study, it emphasises the significance of domain-specific investigations of that dialectical process by which pupils come to know.

Another strong case for the constructivist position, that knowledge restructuring is domain specific rather than domain general has been made by Carey (1985). In a major systematic set of case studies of the acquisition of biological knowledge by children, age 4-10, she argues that 'cognitive development consists,.... of the development of new theories out of older ones with the concomitant restructuring of the ontologically important concepts and emergence of new explanatory notions.' She portrays children as having relatively few theory-like conceptual structures and that the restructuring is domain specific. Using data from a replication of Piaget's animism studies, she shows that children have no simple characterisation of living things, and that the methods by which children generate their judgements of whether objects are alive or not, does not differ in kind from adults. Moreover, whereas Piaget considered the essential development in their thinking to be one where intentional causation, attributed to humans and living objects, is separated from mechanical causation (for inanimate objects), she argues that it is the *growth in the child's biological knowledge* that enables the evolution of their thinking. Quoting Smith (1979) and her own work, both of which show that children of age 4-6 are capable of making deductive inferences, she argues that their failure to make such judgements in the context of her research is because they lack biological knowledge on which to make appropriate deductions. Thus what they are capable of depends on 'what they bring to the inferential task and not on any general inferential capabilities'.

Instead, Carey portrays the process of development as one of theory-change in which an intuitive biology emerges from a naive psychology. She distinguishes between theory-change which is weak, in the sense that there is simply a shift from novice to expert through more detailed articulation and elaboration of basic concepts, and strong restructuring. The latter requires changes in the domain of phenomena to be accounted for; changes in explanatory mechanisms, and changes in individual concepts. As her data show that both differentiation and coalescence of taxonomic categories i.e. the emergence of new ontologically basic concepts has been achieved, by children between age 4 and 10, she tentatively postulates that, since one of the features of strong restructuring is evident, such a change has occurred.

Her case against developmentalism, is that her evidence, and some of Piaget's, is more consistent with the idea that the growth in the child's capabilities is dependent on domain-specific changes in their knowledge rather than any domain-general cognitive change. She speculates that the child begins with a subset of adult explanatory mechanisms - a naive physics and a naive psychology. The acquisition of context-specific knowledge enables the process of theory restructuring and the development of new conceptual structures. If Carey is correct, then the implications are that science education should concentrate on the development of domain-specific knowledge as this is the foundation of new conceptual understanding.

Further substance is lent to this view by Vosniadou (1991) who contrasts the scientific view of the Earth, Sun and Moon with children's naive cosmology. From a constructivist perspective, she argues that the child's knowledge is based on certain experiential beliefs and that development of the adult concept requires radical change in the child's ontology. Face validity to her argument comes from her consideration of the theory change required, summarised in Table 2.8.1.

Feature	**Intuitive Understanding**	**Scientific Understanding**
Size of Solar Objects	Earth is larger than the Sun and Moon which are larger than the stars	Stars are suns which are larger than the Earth which is larger than the Moon
Shape of Earth	Earth is flat	Earth is spherical
Movement of Earth	Earth is stationary	Earth rotates on its axis and moves around the Sun in an ellipse.
Solar System	Rotates around the Earth (geocentric)	Rotates around the Sun (heliocentric)
Day & Night	Sun moves rising and setting	Earth moves, Sun stays still
Gravity	There exists an absolute down at right angles to the plane of the Earth and sky	Towards the centre of the Earth.

Table 2.8.1: Table showing the main features and of an intuitive epistemology and the scientific view of the Earth and Sun.

Further insight into children's reasoning has been provided by the work of Bliss et al (1989) and Mariani & Ogborn (1991) which Ogborn (1994) has elaborated as 'commonsense realism'. Bliss suggests that children will often resort to two common explanations for why things do or don't move which she calls 'support' and 'effort'. Such reasoning is extensively applied to static and dynamic situations to develop a naive physics. Moreover, the use of such reasoning would also account for why infant[5] children think that all you need to light a bulb is a single connection between the battery and bulb. Faced with a novel situation, they resort to commonsense reasoning and familiar metaphors from other domains to interpret new experiences. Thus, the wire enables the battery, seen as the source of 'effort', to act on the bulb, the object, and the child's behaviour is consistent with a constructivist view of learning which would explain such reasoning as the child attempting to interpret new phenomena in terms of their existing schema.

Fianally, in the search for the origins of children's thinking, constructivism has had a seminal influence in exploring the social construction of knowledge and the role of language in the developments of the child's epistemology. As such it has focused on how meaning is created inter-subjectively rather than intra-subjectively. For the child, the problem is one of interpreting and making sense of the form of discourse offered by their science teacher. A good model for the nature of the problem is to be found within the hermeneutical tradition which can be loosely defined as an attempt to interpret the culture of others. Essentially the model of the hermeneutic process is translation, where meaning is not confined to the word alone but is built from the context of its use and the associations it has for the user. Gadamer, (1979), a major proponent of hermeneutics, is concerned to emphasise the importance of tradition which he sees as fundamentally formative in our reasoning. The important aspect of Gadamer's argument is that tradition is intrinsically part of language so that language, meaning, action and context are inexorably bound. A point illustrated by Harré's analysis of the perlocutionary role of scientific discourse where he argues that:-

> The 'logical' properties of discourse such as entailment or consistency are used as part of the criteria by which scientific productions are assessed in the community's system of credit. They appear as essentially moral properties of an agonistic scientific discourse or debate. We can look upon it as one of the many language games that make up the form of life.'
>
> (Harré, 1990), p94

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5 Throughout this thesis, the term 'infant' is used to describe children of who are in the first two years of primary schooling and ages lie between 5 and 7.

Thus the child's problem in apprehending scientific language is not simply one of ascertaining meaning, but comprehending what is a fundamentally different form of discourse with its own implicit values. Weinsheimer (1985) in a commentary on Gaddamer's major work, *Truth and Method,* recognises this aspect when he argues that 'understanding is not automatic, whenever it does occur, it involves interpretation - understanding is never immediate but on the contrary always mediated by interpretation.' Such is the process that the child must undertake when confronted with new experiences and concepts in the texts of science.

But in so doing, the child must resort to words and concepts which are near at hand, and in their context, those available and in common usage are often employed without thought to where they come from, or whether they are apt and appropriate. Thus the child must draw on the language of the concrete and common sense, for the community they inhabit *is* essentially concrete and bound by those traditions. And like all beings, they must resort to familiar metaphors to construct new ideas and representations, a point echoed by Weisenheimer -

> 'metaphor is a specifically linguistic process of concept formation, since a concept is altered or expanded when a word is transferred from one thing to another so that the new becomes intelligible.'
>
> Weinsheimer (1985), p 216.

Metaphor is not simply a useful adjunct for scientific thinking but, as Hesse (1963) shows, an essential component of theory itself which leads to the discovery of hidden causes, or the postulation of new theoretical entities, and therefore is a key tool for the construction of new understanding. Ziman (1969) too makes a similar point, portraying the methodological component of scientific epistemology as one in which 'maps' are created to store and represent scientific information. Although these maps are metaphors, they rapidly become internalised to the point that they acquire the status of a concept or a picture of reality itself. Similarly, Harré (1986) basing his arguments on Soskice's (1985) theory of metaphor also emphasis the vital use of metaphor in the development of scientific knowledge.

> 'Metaphor is a trope through which new vocabulary is created. By means of it our conceptual grasp of a subject matter (referent) is enhanced by the use of a term with a well-established context of use, and thus an existing deep grammar and set of associated commonplaces......In this way, through metaphor, new vocabulary can be created within the existing structure of language, so securing the intelligibility of the term in the context of use.'
>
> Harré, (1986), p 77

If anything, Harré underestimates its role - it is not just a case of developing new vocabulary but the ability to use words appropriately in the correct context that the child must achieve.

Further difficulties with language as used in science have been exposed by the work of Byrne et al (1994) who show how science texts which are apparently simplified, ostensibly requiring a low-reading age, in fact make quite complex demands on a child's reasoning abilities as many of the logical connectives essential to the argument have to be inferred. Basing their work on research by Gardner (1975) that showed that fewer than 70% of secondary age pupils were able to use logical connectives correctly, they devised a set of tests to measure language dependent reasoning skills and pure reasoning, non-verbal competencies. They argue, that the much higher facility on the latter and the lack of correlation between the two demonstrate that 'language difficulties are getting in the way of using reasoning skills.'

Hence in this research, activities which sought to provide children with an opportunity to explore the language of the scientist and the meanings of words were considered to be important.

2.9. Constructivist Epistemology

The central premise of a constructivist epistemology is that knowledge is a human construction. Human beings construct mental models of the world and new experiences are then interpreted in terms of their existing schemata or 'scripts' (Schank, 1982). Thus models of reality are constantly tested against experience and their fit assessed. Consequently they are modified when there are mismatches. This position is articulated by a leading exponent of a constructivist epistemology, Von Glaserfeld who states:-

> " The cognitive organism tries to make sense of experience in order to better avoid clashing with the world's constraints....Basically to have 'learned' means to have drawn conclusions from experience and act accordingly"
>
> (Glaserfeld, 1987, p 8.)

The interpretation of Glaserfeld's use of the word 'experience' is broad - that is as well as being of the first hand phenomenological variety, some experiences may be communicated via secondary sources such as books, being told or from visual media.

Furthermore, consistent with the principles of the generative learning model (Osborne & Wittrock, 1983 - see section 2.8), this experience or stimuli has of itself, no inherent meaning. Existing frameworks act as a filter attaching significance to some experience and ignoring others. Most importantly, the learner must be *active* to construct new meaning, interpreting new experiences in terms of their existing ideas.

In the preceding paragraphs, the construction of meaning is portrayed as an event that takes place within the mind of the learner and is defined as *personal constructivism.* This is to be contrasted with *social constructivism* which argues that meaning is determined more by a process of negotiation of meaning by, and through language to achieve an intersubjective consensus. In essence the distinction is one of emphasis - whereas in the former, knowledge production is subjective and individualist, in the latter it is social and dialectical. Social constructivism has its theoretical roots in the work of Vygotsky (1962), the hermeneutic approach of Gadamer (1979) and latterly O'Loughlin (1992) and (Resnick, 1991), and its empirical justification in the field work of individuals such as Barnes (1976). Reality is constituted in the everyday flow of communicative interaction which sustain our living traditions and concepts. Its strong identification with language as the principal instrument for the development of cognition is typified by the following statement.

> 'Language exceeds consciousness, not only because it makes possible the objectification of every being in the world, every possible object of consciousness, but also because it reveals the absolute, irrelative world, and this is not an object of consciousness. The language world can be understood, but only from within, by living in it, and therefore not objectively.'
>
> (Weinsheimer, 1985), p 248

In approaching the development of a pedagogy for this research, the position taken in this thesis has been to give more emphasis to activities that facilitate the personal construction of knowledge, but to recognise that language and discussion are contributory components which enable the construction of meaning.

Whilst it is recognised, with hindsight, that there are a number of criticisms (Osborne, 1993) of such personal constructivism which will be discussed in considering the conclusions of this work, the idea that the learner is the architect of their own knowledge is the fundamental tenet which has guided the formulation of the pedagogy used in this study.

2.10. A Constructivist Pedagogy

This view of knowledge implied by a constructivist epistemology has serious consequences for teaching and learning which are explored here to elaborate a set of principles guiding the pedagogy used in this research.

Essentially constructivism shifts the emphasis from a didactic, transmission model, where the teacher disseminates information and knowledge to pupils who are considered to be uninformed, to one where learning is a process of changing concepts which already exist in the student. For the teacher, it implies a preliminary process of recognising that pupils may have 'preconceptions' (Ausubel, 1968), which will affect their interpretation of new concepts. Thus an initial period of elicitation and self-reflection, prior to instruction, provides an opportunity for pupils to articulate any existing theories and models they hold. For the teacher, it provides insights into the child's frame of reasoning and is also an opportunity to assess their level of understanding for formative purposes. More importantly, for the child to change their ideas, Hewson and Hewson (1984) argue that a period of self-reflection and externalisation of their thinking is an essential aspect for creating dissatisfaction with existing concepts - for only if the child is consciously aware of their existing ideas can they become dissatisfied.

The creative challenge for the teacher is then to provide a programme of activities and opportunities to challenge pupils' existing conceptions and progressively restructure their thinking towards the scientific conception.

For the pupil, the process requires that they must be *active* in constructing their own understanding of the ideas and experiences that they encounter in the classroom and that they must take an element of responsibility for their own learning (Osborne & Wittrock, 1985). Posner et al (1982) made a significant contribution to the elaboration of a constructivist pedagogy by setting out a set of conditions which must be satisfied for conceptual change to occur when the pupil encounters a new phenomenon or experience. The new concept must be *intelligible* - that is does it make sense? Can he or she construct a coherent conceptual representation of the phenomenon being studied? It must be *plausible* so is it judged to be true and is it reconcilable with existing conceptions. Finally the new conception must be *fruitful* - so is it useful? Does it clear up existing anomalies and does it have predictive power? Only if all of these conditions are satisfied is it likely that conceptual change will occur.

Another influential model of a 'constructivist approach to curriculum development' has been developed by Driver (1985; 1989b). This model of teaching and learning consists of five phases.

Orientation	Teacher demonstration of some relevant eye-catching or thought provoking phenomenon.
Elicitation	Students work collaboratively to explore their existing understanding of relevant phenomena e.g. how plants grow, how air in a syringe can be squashed. Ideas are fed back through a group poster presentation to other students.
Restructuring	
a. Clarification and Exchange	Students review their own ideas and others. They are then asked to generate theories that might describe the phenomena.
b. Exposure to conceptual conflict	A series of demonstrations, models and investigations then take place which are designed to explore and consider the alternative models that have been elicited from pupils.
c. Construction of new ideas	Issues emerging from these experiences are discussed by pupils and the teacher and evidence is considered.
d. Evaluation	Different models are reconsidered and evaluated so that a consensus may emerge focused on the scientific conception.
Application	Pupils are given the opportunity to try out the new ideas in order to explain new situations.
Review	Pupils revisit their earlier work and comment and discuss any changes in their thinking.

It is notable that this scheme is vague on the issue of how the scientific idea will arise if it is not generated by the pupils, Driver and Oldham merely stating that the teacher will present it 'at some point'. Moreover, this model has been formulated to meet the needs of the secondary classroom and is too prescriptive for the context of the primary classroom where children are often working on small groups at different tasks.

An approach that has more relevance to the primary classroom has been explored by the Learning in Science Project (Osborne & Biddulph, 1985) in New Zealand. This project developed an 'interactive' model of teaching which they saw as an amalgam of the discovery, transmission and process approach. The term 'interactive' is used to denote the notion of teaching as a process in which their is an 'interchange of talk among people who respect each other's ideas' and this begins 'with a genuine desire to know what a child thinks (and why).' This model has at its core, seven procedures which are designed to promote the negotiation of meaning around a focus of children's questions, investigations and critical reflection. The approach aims to develop the 'skills needed to ask better questions, plan and carry out investigations and construct and communicate ideas.' Whilst, this was a substantive project, the criteria that it uses for the determination of content based on everyday events, children's prior knowledge and the use of simple investigations are somewhat vague and the report has no quantitative data to justify its use.

From a slightly different perspective, Posner (1982) offers a more useful approach, arguing that learning should be seen as a task-oriented process. Students bring to tasks a set of internal resources and are provided with external resources, but it is how they engage with the task and construct its purpose for themselves which determines how much they learn. Raising a cautionary note that:-

> 'even if students bring adequate resources to tasks they often need to be shown how to use their resources in accomplishing tasks. Often students possess intellectual resources that have the potential for helping them accomplish tasks, if only we knew how to use them. This could be considered a problem of accessing existing knowledge. Good examples, analogies, models and metaphors may be powerful teaching techniques because of their potential for helping students gain access to the relevant existing knowledge in dealing with a new task.' Posner (1982), p 346

He goes onto argue that the curricular task becomes one of -

- defining one or more learning goals; these are not behavioural objectives but changes in the internal representations held by the students.
- devising a set of expected operations associated with the tasks; tasks are selected because outcomes may be idiosyncratic, diverse and educationally rich.
- producing a set of external resources;
- eliciting the student's internal resources and applying them to the task.

And it is these principles, which have broadly guided the formulation of a pedagogic strategy in this research.

But Posner's work raises another set of queries which he himself acknowledges. What are the appropriate curricular tasks? What representations do students construct from their work on these tasks? What internal resources do students bring to tasks? This research is an attempt to find some answers to such questions.

Other workers who have explored such approaches to changing children's conceptions are Nussbaum and Novick (1981), Cosgrove et al (1984) and Gunstone et al (1981). A useful contribution is provided by Marton and Ramsden (1988) who review many of the suggested teaching strategies for conceptual learning. In summary, it is possible to see the following principles forming the basis of an emergent constructivist pedagogy which forms the basis of the intervention work carried out in this study.

1. Elicit the student's prior conceptions and provide an opportunity to make them explicit.

This principle is a fundamental tenet of a constructivist approach to teaching. Children's conceptions are diverse and context specific and children may not recognise the need for internal coherence. Their theories form the 'spectacles' (Pope, 1985) through which children view the world. They are not static, observable, discoverable truths, but dynamic, evolving creative ideas and change will be assisted by giving the child opportunities to become conscious of their own thinking. Therefore, the elicitation of children's thinking serves a range of functions in this research: to make the child conscious of their own ideas and reasoning; to sensitise the teacher to the internal representations that the children bring to the phenomena; and for the purposes of formative assessment to help plan learning experiences which are both appropriate to their current level of understanding and challenge their existing ideas.

2. *An analysis of learning goals*

Aims and their objectives are an essential and traditional feature of any curriculum planning. Thus, any attempt to develop a child's concepts needs to be based on a definition of what a preferred understanding would be. In the earlier phases of this research on children's understanding of light and electricity, a list of concepts was compiled by the team to provide a map of ideas considered an *a priori* necessity for the development of the scientist's world view. However, in the case of their understanding of the processes of life and astronomical concepts, the National Curriculum Order had been published (DES, 1989). This Order defined, in a set of attainment targets, learning objectives for children to achieve through the age range in a progressive, developmental fashion. Whilst the Order and their articulation of the targets within it are open to debate, they represented at the time, the standard objectives that many teachers would be using for their teaching. Hence the decision was made to adopt these statements as guidelines of what it might be reasonable for a child to be expected to know. This does not imply that these statements are accepted as sensible or possible. The research set out to ask whether these learning outcomes were achievable by the majority of children using a constructivist pedagogy.

In the context of this research, although the emphasis lies on the achievement of content goals, the approach is based on the integration of content and process. It is argued that the opportunity to 'do science' or 'act like scientists' enables children to see that scientific explanations are human constructions and not absolute facts.

3. *Focus on relevant critical issues and use these to challenge or highlight the inconsistencies and consequences of pupils' conceptions.*

The identification of learning goals enables critical concepts essential to a scientific understanding to be identified. Therefore, for children who hold 'alternative conceptions', their overthrow requires children to move through a phase in which the mismatch between their existing explanatory schema and newly experienced phenomena provokes a 'cognitive conflict' or state of 'mental disequilibrium' (Posner et al., 1982). Whether this requires 'revolutionary' change (Gilbert & Watts, 1983) in the Kuhnian sense, or whether it requires 'evolutionary' change, in the sense that Carey (1985) describes, through the accretion of additional knowledge and the extension of precision of meaning is a matter of some debate. Certainly research (Cosgrove et al., 1984) shows that although conceptual conflict may facilitate change immediately, without further reinforcement, many children revert to their previous conceptions. Rowell and Dawson's (1983) work also showed that many children will often construct auxiliary hypotheses to explain anomalous behaviour. However, their work did show that if children were called onto elaborate their ideas, conceptual conflict was more effective at achieving a change in the child's understanding. Thus the presentation of conceptual challenges is an important mechanism for perturbing the child's thought. For as Conran (1983) argues,

> "Young children, for example, commonly predict that a stone will float 'because it is heavy.' Sooner or later, this simple 'theory', that heavy things sink and light things float, is challenged by an anomaly, perhaps, a heavy tree trunk floating and a grain of sand sinking. A new theory may develop - wooden things float but stones sink."
>
> Conran (1983) , p 24

Taken with other reported results (Champagne, Klopfer, & Anderson, 1980; Stavy & Berkovitz, 1980) which indicate some success with such a strategy, such approaches must form part of the repertoire of any approach to pedagogy for science education and does so in this research.

4. Present the learner with new ways of seeing.

Generating conceptual conflict, of necessity, requires children to be presented with new ways of seeing. The scientific conception (or one closer to it) may emerge from preliminary discussions with children as reported by Nussbaum and Novick (1981). However, if such thinking fails to emerge for consideration, the teacher will have to introduce the ideas themselves, for as Driver (1983) states:-

> "The theoretical models and scientific conventions will not be 'discovered' by children through their practical work. They need to be presented. Guidance is then needed to help children assimilate their practical experiences into what is possibly a new way of thinking about them." ,
>
> (Driver, 1983), p 9

Thus, in this research, teachers were asked that, as well as testing their own ideas, children should have the opportunity to test the 'right' idea. Children would be given an activity whose solution required the correct application of a scientific idea, thus challenging any existing alternative conceptions. It was hoped that any conflict would help children to develop their understanding towards the scientific conception.

Furthermore, in some areas of scientific knowledge, such as astronomy, there is only limited scope for practical investigations. Thus teachers were asked to turn children's ideas into enquiries which could be directed at books or other secondary sources of information. Other phenomenological investigations are difficult for young children because changes are not easily perceived and teachers were encouraged to find ways of making the imperceptible, perceptible. For example, the fact that the Moon goes through regular changes in phase could be established by collecting daily records of its appearance as a class wall chart.

5. Place more emphasis on discussion in small groups

The role of talk in exploring the nature and meaning of language has been highlighted by Barnes (1976). Language and its use in social interactions is the basis for the sharing and elaboration of meanings, a view expressed, from a sociological perspective by Schutz and Luckman (1973).

> 'There is a phenomenological approach to a taken-for-granted world of happening in which our experiences are assumed to be inter-subjective and built into a stock of knowledge which is shared. This sharing, by means of social exchanges, continually reinforces the meanings embedded in our thought and language.'
>
> Schutz and Luckman (1973), p 68

Further support for the role and value of language comes more recently from Sainsbury (1992) who, quoting the philosopher Gadamer's (1979) conception of this process as a 'fusion of horizons' argues that

> 'Such a meeting of two perspectives, the fusion of horizons arrived at by negotiation is a new, fuller, and more adequate way of making sense of the world and an increase in the possibilities for future experience. It represents a greater degree of participation in the theory-system, in the form of life. This is what I want to describe as learning.'
>
> (Sainsbury, 1992), p 114

Glaserfeld (1989) too makes the important point that the most frequent source of perturbations for the thinking of the young learner is our linguistic interactions with others.

However, standard pedagogical approaches do not give much priority to the role of discussion and opportunities to practice the use of language in context for research shows that teachers are reluctant to relinquish control of the verbal game of teacher opening; pupil response, teacher follow-up (Edwards & Furlong, 1978) with an over-reliance on closed questions, and that discussion often forms less than 15% of pupil activity within a science classroom (Davies & Greene, 1984). Therefore in this research project, teachers were encouraged to make more use of group activities which encouraged discussion and allowed children to compare and share their ideas and develop their use of language. Typically, children would be asked to sort a group of foods, using criteria agreed by discussion, or alternatively produce a concept map (Novak & Gowin, 1984) using words or pictures. The value of using the latter technique is shown by Horton's (1992) recent meta-analysis of 18 studies of concept mapping that met strict experimental controls. This showed that in 16 of the studies, significant learning gains had been achieved.

Learning science involves learning to see in new ways. The principal instrument for the social construction of reality is language so science draws heavily on metaphor and analogy. Sutton (1992) puts the case that 'selecting a new metaphor is one of the main tools for innovation in thought....Once Harvey saw the heart as a pump ....there were a host of new questions that could be investigated.' Yet the young child's vocabulary is limited and he or she often uses a restricted set of the meanings of words resulting in underextension, e.g.'animal' is often used for the term mammal (Bell, 1982). Alternatively, words are overextended so the term 'melting' is used for the process of dissolving as well as melting. Consequently an aspect of science education is a process of inducting children into new ways of talking about familiar phenomena and group discussion activities provide structured opportunities for linguistic exploration. In such a manner, the meaning of language and ideas can be refined as an understanding of concepts comes through the opportunity to practise and discuss the appropriate use of language in the relevant context. Or as Vygotsky (1962) puts it-

> 'The development of the scientific concept, on the other hand usually begins with its verbal definition and its use in non-spontaneous operations - with working on the concept itself.'
>
> (Vygotsky, 1962, p 192)

It was also hoped that such exchange of ideas and views, as well as generating a better understanding of words and their meaning in a given context, would help children to broaden the range of phenomena to which ideas can be applied - to generalise from one specific instance to another.

6. Using reflective teaching strategies that encourage metacognition.

Several researchers have reported the use of teaching strategies that encourage children to become more self-conscious of their own learning processes and to take responsibility for them (Baird & Mitchell, 1986; Driver, 1989a). Additionally, the use of overt strategies of this nature provides a concrete step-by-step model and mechanism for young children which may help them to become self-reflective, or in Brown's (1987) words, 'the child learns how to learn.'

In an extensive and thorough review of the field, Brown (1987) discusses the meanings of the term 'metacognitive'. Noting that the term has been 'problematic from its inception' she suggest that part of the confusion arises from the fact that it refers to two distinct areas of research: knowledge about cognition and regulation of cognition. Though the two are inter-related, she argues that the research evidence suggests that the former is usually assumed to be achieved only late in cognitive development by individuals capable of reflective abstraction. The latter, however, refers to activities that are used to regulate and oversee learning, such as planning activities, predicting outcomes, scheduling strategies and that the evidence is that such strategies are relatively age-independent. It is in this latter sense that the term is used here. Thus, pedagogic strategies used were asking children to keep personal logs of what they think or questions that they may have, sorting activities that required the criteria to be made explicit, directed reading activities that required the children to work over text and think about the meaning in a given context, concept mapping which required children to articulate the reasons for their arrangement of terms. Such strategies were chosen because of their potential for self-regulation and conscious articulation of thought processes.

Further evidence for the value of such approaches come from the work of Gagné and Smith (Gagné & Smith, 1962), quoted in Brown (1987), which found that forcing learners to state the rules that they were using significantly improved the learning process. Brown also discusses other research that shows that interactions with a supportive other person leads to the development of metacognitive strategies in children. Given that it is difficult in a normal classroom for all children to have sustained interaction of this nature with a teacher, the use of strategies requiring peer-interaction may provide another opportunity for the development of self-regulation and self-interrogation in the child. As she points out, ultimately, it is only 'through the process of internalisation', that is the capacity to reflect on ones own thinking, that 'mature reasoners become capable of providing the supportive role of other for themselves.'

2.11 Research Questions

The evidence and arguments summarised in previous sections suggest that many of children's reasoning patterns are situated in a specific contexts and determined by their pre-existing concepts. These have their roots in a commonsense realism and a language whose traditions and metaphors are constructed from concrete experience. If children's ideas are to be changed or extended, two research questions then arise that would inform the teaching of primary science which are the focus of this study:

- What ideas about particular science concept areas do young children, age 5-11, hold prior to instruction?

- What conceptual change can be achieved through the use of intervention activities that provide opportunities to elicit children's thinking prior to instruction, that attempt to challenge children's thinking and which place more emphasis on the active construction of meaning?

The answer to the first question requires a descriptive, empirical answer. The value of such data will be twofold. Firstly a portrayal of pupils' alternative conceptions which are widely held and their common features, as opposed to those which reflect idiosyncratic individual variation, will raise awareness and understanding amongst teachers of the possible perspectives children may bring to the classroom and the difficulties they may have in accommodating the scientific conception. Secondly, as will be shown in the review of previous research, little work has been done to answer this question for children of age 5-11 *from a constructivist perspective.* Thus this research will contribute new information and understanding about young children's thinking in science. This is not to say that Piaget's ideas are irrelevant to science education, but, at an age when children are experiencing a large range of phenomena Piaget's work indicates that for many, there will not be a fundamental change in their operational schemata. Therefore it is their interpretation of this context-specific information that is more likely to affect their conceptual development than any generalised reasoning capabilities. This position is most near to that of Schank and Birnbaum (1994) who argue that 'one may have the potentiality for intelligence, but without knowledge, nothing will become of that intelligence.' Thus though the young child's capacity to reason is fundamentally distinctive from that of the mature adult, it is contended that the acquisition of new knowledge is a essential foundation to the development of intelligence.

The second question addresses the issue of fundamental concern to science educators. If pupils interpretation of phenomena is important in how they perceive and incorporate new ideas and concepts into their existing knowledge - what form should a constructivist approach to teaching and learning take? Section 2.10 has elaborated the arguments for the specific teaching and learning strategies adopted in this research. These represent an attempt to formulate a pedagogy which both recognises the importance of children's existing ideas and the need to be active in the construction of new meaning. A more critical issue is - what evidence is there of the effectiveness of such an approach? For only empirical data which answers this question will give credibility to constructivist ideas of teaching and learning.

2.12. Summary

This chapter has explored how primary science developed out of the teaching of nature studies to a position where there was -

> "near unanimity amongst English educationalists regarding the psychological principles which underlie the learning of primary science. The basic Piagetian view of children's learning and development has been generally accepted."
>
> (Richards, 1983), p 7.

It has sought to show how dissatisfaction with the implication of those principles, and the principles themselves, coupled with greater socio-political demands for greater control of the curriculum lead to the need for more elaboration of content and an approach to teaching and learning based on constructivist principles. Such a pedagogy would recognise that children's existing ideas are an important aspect to their interpretation of new information and that children need structured opportunities requiring them to actively participate in reformulating their concepts. This research then is an attempt to provide a picture of young children's scientific understanding that would inform teachers and to explore the effectiveness of a constructivist approach to teaching and learning.

3: Methodology

3.1 Methodological Issues

Traditionally, science education research has fallen into two major paradigms - the scientific, characterised by an empiricist approach to the collection of data which seeks causal explanations, and the interpretive which seeks understanding in terms of intentions, motives and stated reasons. Whereas the former is quantitative, the latter is qualitative, basing its evidence on a careful selection of data synthesised to form a narrative whose validity lies with the meaning attached by the reader. More recent analyses of educational research (Popkewitz, 1984; Soltis, 1984) have also identified a third paradigm of critical inquiry which has evolved from the work of critical theorists such as Habermas (1981). Workers in this paradigm 'stress the need for inquiry to take into account the historical-ideological moment we live in' and seek to 'demystify our educational institutions and practices.' (Soltis, ibid).

None of these methodologies are without problems. Miles and Huberman (1984) in the introduction to their book *Qualitative Data Analysis* comment that 'qualitative research badly needs explicit, systematic methods for drawing conclusions' and note that the issues of generalisability and replicability are a major concern for this methodological approach. In contrast, traditional quantitative-analytical approaches which follow the philosophical tradition of logical empiricism suffer from the fact that 'they have been too concerned with *internal* validity and conceptual certainty, coming to grief when their data lacked authenticity and meaning - *external* validity.' (Miles & Huberman, 1984).

But perhaps the best case against the thesis that these traditions are incompatible is made by Howe (1988) who argues from an examination of the four basic components of research - data, design, analysis and interpretation, that the quantitative-qualitative dichotomy does not support the notion of incompatibility. For data, his first point is that the quantification of a categorical measurement does not fundamentally change its nature. Secondly, the contention that the process of quantification requires divests data of its inherent reflection of the subjective and substitutes the researcher's external perspective is not sustainable as, if so, interval data obtained from individuals to rate feelings or instruction could then no longer be considered to be a reflection of the individuals views. At the level of design and analysis, the chief differences between these two schools lies in their focus of interest, i.e. the variables of interest and their methods of measurement and description, and not in the idea that the quantitative researcher is 'objective' or 'scientific' whilst the qualitative researcher is 'interpretive'. For statistical tests, the principal tool in the quantitative researchers methodology, rely on 'making numerous judgements about what counts as a valid measure of the variables of interest....and what statistical tests are appropriate.' Further at the level of interpretation, the quantitative researcher may be bound by their earlier decisions about what to measure, but both researchers construct arguments based on an interpretation of the evidence of the data. Statistical analyses are simply examples of mechanical inferences which are open to alternative interpretations in a similar manner to the judgements of the qualitative researcher. Thus Howe concludes that

> 'the interpretation of results is at most highly qualitative (nonmechanistic) or highly quantitative (mechanistic). That is actual studies invariably mix kinds of interpretation, and whether a given study is termed 'qualitative' or 'quantitative' is a matter of emphasis.'
>
> (Howe, 1988), p 12

Instead quantitative and quantitative methods are 'inextricably intertwined'. Howe argues against the 'tyranny of methodological dogma' and that researchers must give up the notion that social science research is either just like, or fundamentally different from, physical science. Instead, he contends that the traditions are compatible and researchers should proceed on the pragmatic criterion of 'what works' basing his epistemology on a qualified adherence to the position outlined by Rorty (1982) and Bernstein (1983). Reichardt and Cook (1979) go so far as to argue that a mixed methodology is the first logical choice and that 'those who advocate an evaluation plan devoid of one kind of information or the other carry the burden of justifying such an exclusion.'

The research described by this thesis is of such a nature. The research questions are fundamentally empirical since they are not based on a well-defined hypothesis. For the first, an understanding of children's thinking and their conceptions will only come from a close examination of the data collected from the range of responses, and an attempt to extract and reconstruct the features of their ideas. The second question, which is attempting to explore the potential of a constructivist approach for teaching and learning, was deliberately not framed as a hypothesis as the aim was to provide a description of possibilities, rather than make generalisable claims about the effectiveness of this approach. This was intentional as the methodological limitations meant that any result obtained from a controlled experiment would have had little validity.

In essence the research adopted a mixed methodology of quantitative and qualitative work. It was qualitative in that it sought to achieve 'ecological validity' by locating the work firmly in the primary classroom, using ordinary primary teachers to conduct the intervention work and to assist in the process of data collection. Thus as Sherman and Webb (1988) have argued, it recognises the importance of *context* and that these contexts must 'not be contrived or constructed or modified' if the research was to have meaning for its intended audience of primary science educators and interested teachers. In this it sought to avoid the possible trap identified by Sherman and Webb (1988).

> "Certainly quantitative research generates abundant information and relationships. But what does it tell the teacher to do? Because that can only be determined in a qualitative context - a real, direct, specific, explicit and problematic context - the quantitative researcher is - and perhaps must be - mute. "
>
> Sherman and Webb (1988), p 8

Its qualitative nature is also characterised by the lack of a definitive hypothesis for testing. For as Sherman and Webb (1988) argue - 'the aim of qualitative research is not the verification of a predetermined idea, but *discovery* that leads to new insights.' Thus, although the research was approached with the belief that a constructivist pedagogy might have some value for primary science education, the intention was more to explore what the potential such an approach had for learning and conceptual development, as well as its inherent problems and difficulties.

The study *is* also qualitative in that the data are categoric and classified by a subjective and iterative process of interpretation by the researchers. The work is *not* qualitative, or ethnographic, in seeking to avoid generating guiding questions prior to the enquiry, but it is in the sense that it seeks to 'identify themes' in children's thinking 'as they are suggested by the data' (Bogdan & Taylor, 1975) and attempts to demonstrate support from the data for these themes in children's thinking. Thus its serious purpose is an attempt to understand children's frameworks and ideas using their conceptual categories.

Marton (1988) has aptly described such research as 'phenomenography' which he portrays as an approach where 'an effort is made to uncover all the understandings people have of a specific phenomenon and to sort them into conceptual categories seeking not to 'try to describe things as they are' but rather 'to characterise how things appear to people.'

In essence, this research shares many features of what has become known as 'action research'. Cohen and Manion (1989) view such research as having the following tangible features: action research is situational, collaborative, participatory and self-evaluative. In that this research is attempting to explore the potential of a constructivist pedagogy for learning in the context of urban primary schools, using an approach which requires teachers to undertake the intervention work with children, there are strong similarities. The research is also concerned with 'innovation and change' aiming to 'improve in some way a given set of circumstances' - in this case the teaching of primary science.

However, the research *is* quantitative in that it attempts to use quantitative methods as an aid, or a tool to describe the broad features of children's thinking in a summary form. It is also quantitative in that the research seeks to use statistical methods to describe aspects of the changes that occurred before and after the intervention, and to analyse the relations that exist between children's ideas. In summary, the approach adopted in this research is a mix of methodologies sharing Howe's view that

> "Although the distinctions between quantitative and qualitative methods ....do mark important differences, the differences do not constitute sharp, uncrossable dividing lines."
>
> (Howe, 1985), p10.

Robottom and Hart (1993) too recognise this division and make the additional point that the referent discipline for science education research is not applied science but educational research which typically adopts a range of approaches. However they argue that the debate is not really about methodologies 'but in the assumptions which prefigure what is to count as appropriate research topics.' They argue that different strategies for data collection rest on, and express, different ideologies. Thus they conclude that the adequacy is to be determined at a meta-level in the relationship between the ideology of the methodology and the ideology of the research questions. They see participatory educational research as a political activity and seek research to ask of itself and explore the nature of the power relationships between the constituencies engaged in the research, the ideological underpinnings of the research, the extent to which it is able to control the goals of the research and also, maintain a critical, self-reflective stance.

In terms of such a perspective, this research has an implicit commitment to the notion that learning in science can be improved. Whilst this has been the subject of debate (Chapman, 1991; Claxton, 1993; Claxton, 1986), it has not been the focus of research and the assumption rests on the reported state of affairs (DES, 1983) and a belief born of experience and reflection. In attempting to engage ordinary teachers in the work, it has sought to negotiate aspects of the methodology with some of the participants, and in drawing its concluding marks it has attempted to be critically self-reflective of its underlying assumptions. Its epistemology is driven by a choice of methods that attempt to achieve accuracy in describing children's thinking, reliability in avoiding the worst excesses of subjectivism and comprehensiveness in using a mix of methods to collect a wide range of data from children.

3.2 The Sample

Schools from the London area were chosen for this research from three local authorities (Inner London, Newham and Barnet). Each phase of the research project required 6 classes of children, two for each phase studied - infants, lower juniors and upper juniors. A maximum of two classes from any one school were used and always from a different phase. Thus the use of two classes for each phase, generally produced a sample of children from differing socio-economic strands because of the school location, and ensured a minimum sample size of 25 after losses due to children present for the pre-elicitation being absent at the post-elicitation. The majority of the schools were selected by the project research officer who had previously worked in the locality providing support to primary schools for the teaching of primary science and through informal contacts. Individual teachers were approached to ask if they were interested in taking part in the research project. Others were identified by a science adviser in their Local Education Authority and an initial meeting with Head Teachers of the participating schools established the schools' willingness to collaborate and the possibility of teachers being released for occasional meetings was agreed. The implication was that teachers' participation was recognised and valued by their employing authorities and headteachers. For the teachers it was anticipated it would be an opportunity for enhanced professional development.

Each school was allocated to one member of the research team who worked closely with the teacher throughout the research phase. Many of the teachers took part in more than one phase of the research and this was helpful in developing a good understanding of the methodology and philosophy of the research project.

3.3 Phases of the Research

The research work was organised into the following phases

Phase 1	Pilot Phase
Phase 2	Exploration

Phase 3	Pre-Intervention Elicitation
Phase 4	Intervention
Phase 5	Post-Intervention Elicitation

Each phase, particularly the pilot work, was regarded as developmental; techniques and procedures were modified in the light of experience, and in discussion with teachers. The modifications involved a refinement of both the exposure materials and the techniques used to elicit ideas. This flexibility allowed the research team to respond to unexpected situations and to incorporate useful developments into the programme.

3.3.1 The Pilot and Exploration Phase

The pilot exploration phase was based on interviews with a small number of children, generally twenty. Items and interview tasks were drawn from a literature review in the domain of enquiry, undertaken to establish what was already known about children's thinking, and from ideas suggested by the research team. Previous research is discussed in section 4.2, 5.2, 6.2 and Appendix 3.

The pilot interviews used a wide range of questions to explore the nature of children's understanding of the domain and its associated concepts. In addition, drawings and answers to written questions were employed to examine how valuable and reliable such sources were for eliciting children's meanings and understanding. The exploratory nature of this phase was required to supplement what little literature there was available on the nature of young (5-11) children's understanding of this topic and to explore how suitable the questions were for eliciting children's conceptual understanding. At the end of this phase, the data were examined to determine which were the most valuable lines of approach for eliciting children's ideas about this topic. Such data are inherently categoric and qualitative, but this phase was useful for exploring those methods which were fruitful in producing data efficiently that would provide a comprehensive picture of children's thinking from a variety of means. The range of methods enable a more reliable picture of children's thinking to be constructed.

The other valuable feature of this phase was that it provided time for developing a relationship with the teacher and the children so that they could become accustomed to the mode of working required. In the Exploration phase children engaged with activities set up in the classroom for them to use, without any direct teaching. The activities were designed to ensure that a range of fairly common experiences (with which children might well be familiar from their everyday lives) was uniformly accessible to all children to provide a focus for their thoughts. In this way, the classroom activities were to help children articulate existing ideas rather than to provide them with novel experiences which would need to be interpreted.

Each of the topics studied raised some unique issues of technique and these distinctions led to the Exploration phase receiving differential emphasis. Topics in which the central concepts involved long-term, gradual changes, such as 'Growth' (undertaken by Liverpool University), necessitated the incorporation of a lengthy exposure period in the study. A much shorter period of exposure, directly prior to elicitation was used with topics such as 'Light' and 'Electricity' which involve 'instant' changes.

3.3.2 The Elicitation of Children's Thinking

A range of methodologies were used to elicit children's thinking which were as follows:-

i. *Using Log-Books (free writing/drawing)*

Where the concept area involved long-term changes, it was suggested that children should make regular observations of the materials, with the frequency of these depending on the rate of change. The log-books could be pictorial or written, depending on the age of the children involved, and any entries could be supplemented by teacher comment if the children's thoughts needed explaining more fully. The main purposes of these log-books were to focus attention on the activities and to provide an informal record of the children's observations and ideas.

ii. *Structured Writing/Annotated Drawing*

Because of the size of the sample, it was not possible to interview all children individually. Instead, items were produced which required children to use either writing, annotations to drawings or their own drawings to explain what they thought had happened. Drawings were particularly revealing when children added their own words to them. The annotation helped to clarify the ideas that a drawing represented. The researcher also asked children to clarify their diagrams and added explanatory notes and comments where necessary, after seeking clarification from children. The questions used for each domain are given in Appendix 4a, 5a, 6a and 7a.

iii. *Completing a Picture*

Children's drawings as expressions of their thinking and ideas were used extensively. Care had to be taken to ensure that children appreciated that it was their ideas that were being sought, not their artistic expression and children were often asked to add or annotate drawings to show for instance, what happened to the food they ate or how the light travelled between their eyes and a book; some annotations were added by the teacher in those instances in which children lacked the writing skills to do so themselves.

iv *Sorting activities*

These were found to be valuable in eliciting children's thinking in some instances. For instance, children would be asked to sort sets of cards containing the names of objects and animals into living and non-living or to group foods into healthy and non-healthy. The children's groupings, and their rationale for their choices provided valuable insights into their thinking.

v. *Individual Interviews*

In any instances where children had difficulty in expressing themselves in writing, which was generally the case for infant children, their thinking was elicited through the use of individual clinical interviews. This provided an opportunity to probe some of their thinking further.

After the data had been collected, it was shown and discussed with the teacher to provide them with some insight into the range of ideas and concepts held by the children about the domain. This insight was then used as a basis for planning the work for the intervention phase.

3.3.3. The Intervention

The starting point for much intervention work was questioning which moved from being open-ended to seeking justification and evidence to support beliefs expressed by children. Teachers used ideas expressed by children during the elicitation phase as a starting point and thus their thinking remained the focus of interest. Constructivism rests on the assumption that individuals generate their own theories and explanations, some of which are acquired through cultural experiences. Moving to the intervention phase did not mean abandoning respect for the child's ideas and autonomy. Therefore care was taken to describe interventions in terms of 'helping children to develop their ideas' rather than 'developing children's ideas'. The distinction may appear subtle but it is significant and important in the context of this research.

The nature of the management role which teachers were encouraged to adopt is presented schematically in Figure 3.1. Although the approach can be described as 'child-centred', each teacher had a clear conceptual agenda defined in terms of what a preferred understanding for a child of this age would be - a set of 'learning goals' which were defined by the research team in co-operation with the teachers (see section 4.3, 5.3, 6.3 and 7.3). Thus, teachers encouraged children to work within a prescribed conceptual domain.

The starting point was to set the context by providing experiences which would engage children and encourage them to reflect on their own understanding.

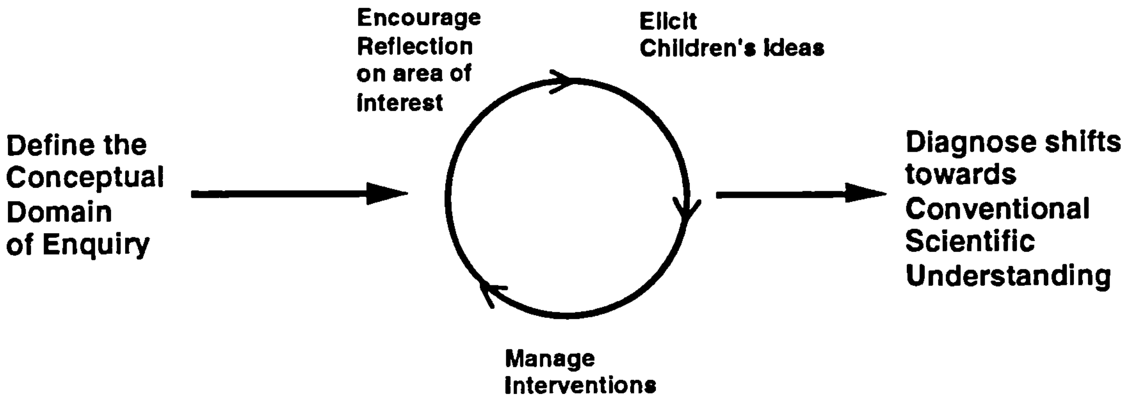


Figure 3.1 Schematic Representation of Teacher's Role in a Constructivist Classroom Regime

In an attempt to implement the basic epistemological and pedagogical stance outlined in both this and the previous chapter, one of the fundamental requests made of teachers was that they should make every effort to listen to children. Teachers initially found it difficult to take a more open-ended and less transmissive role. Even those teachers who were able to empathise with children's views found it hard to hold back from correcting them or handing over the conventional scientific explanations of the phenomena under consideration. However, for some teachers the discovery that children held well-defined explanations for physical phenomena, albeit scientifically incorrect, was a fascinating revelation. And, once the efficacy of managing learning by harnessing children's own motivation to find out and make sense of things for themselves was experienced, they tended to be more sympathetic to the approach. It was felt that the teachers of younger children, in particular, accommodated this approach more rapidly, perhaps because they are more accustomed to the struggle of understanding young children's point of view, given that these tend to be further removed from adult perspectives than is the case with older children.

The teacher's next step is to encourage and enable children to make their ideas explicit. At this point, the expression of ideas was welcomed and all ideas are accepted as provisional. It would not be accurate to describe this activity as one in which 'misconceptions' were identified; what was being identified was the child's ideas and these are not treated as right or wrong, but as valued expressions which can be accepted conditionally. Teachers were then asked to move to a phase in which children are required to support and justify their ideas by adducing evidence of some kind. The longer-term acceptance of the ideas by the teacher and the class group will be conditional on supporting evidence; ideas are subjected to scrutiny and validation. Some may be ephemeral; others may be the subject of lengthy enquiry.

The research team produced a general framework to guide the structuring of activities appropriate to the class based on the principles elaborated in Chapter 2. These strategies were:

a) *Encouraging children to test their ideas.*
It was felt that, if pupils were provided with the opportunity to test their ideas in a scientific way, they might find some of their ideas to be unsatisfactory. This might encourage the children to develop their thinking in a way compatible with greater scientific competence.

(b) *Encouraging children to develop more specific definitions for particular key words.*
Teachers asked children to make collections of objects which exemplified particular words, thus enabling children to define words in a relevant context through using them.

(c) *Encouraging children to generalise from one specific context to others through discussion.*
Many ideas which children held appeared to be context-specific. Teachers provided children with opportunities to share ideas and experiences so that they might be enabled to broaden the range of contexts in which their ideas applied.

(d) *Finding ways to make imperceptible changes perceptible.*
Long-term, gradual changes in objects which could not readily be perceived were problematic for many children. Teachers endeavoured to find appropriate ways of making these changes perceptible. For example, scattering dust into a torch beam shows up the beam.

(e) *Testing the 'right' idea alongside the children's own ideas.*

Children were given activities which involved solving a problem. To complete the activity, a scientific idea had to be applied correctly, thus challenging the child's notion. For instance, children would be given a bulb, a battery and some wire and asked if they could get the battery to light the bulb. It was hoped that such problems might challenge any alternative conceptions the child had and assist the development of a more scientific idea.

(f) *Using secondary sources.*

In many cases, ideas were not testable by direct practical investigation. It was, however, possible for children's ideas to be turned into enquiries which could be directed at books or other secondary sources of information. This method became particularly significant when working on astronomy.

(g) *Discussion with others.*

The exchange of ideas with others could encourage individuals to reconsider their own ideas. Teachers were encouraged to provide contexts in which children could share and compare their ideas. Thus in a sorting activity, groups of children would be called onto justify to others the reasoning behind their choices which would become a focus for discussion.

Additionally, a set of possible activities based on these principles were written and provided for teachers who felt less secure with this approach. Full details of the activities suggested for each area can be found in Appendix 4b, 5b, 6b and 7b respectively

3.4 Working with Teachers

The method adopted was collaborative research between teachers and University-based researchers i.e. John Meadows from the then Polytechnic of the South Bank, the project officer and the author. None of the teachers had any special expertise in science.

One group of about six teachers pursued enquiry working through all the phases of the research with the assistance of the researcher over a period of 6-12 weeks with the support of group meetings and occasionally, classroom visits. An attempt was made to have a sequence of teacher meetings which would have the following functions:

1st Meeting: The introduction and definition of the domain of enquiry; the exploration and support of teachers' own understanding of the science; the determination of an agreed set of elicitation activities by negotiation and discussion with the teachers.

2nd Meeting: Reporting the outcomes of the elicitation activities across the range of participating age groups of children. Discuss broad possibilities for interventions, in the light of the kinds of ideas and sequences in ideas emerging

3rd Meeting: Provision of feedback about the quality and efficacy of the classroom interventions designed to help children to develop their ideas in the direction of conventional scientific understanding

4th Meeting: Critical review of the outcomes of all phases of research within the domain and summary of the lessons learned for future classroom work in the same area.

Unfortunately, the local authorities were unable to release any of the teachers due to the difficulties experienced during this phase in obtaining any supply cover in the London area. This meant that all meetings had to take place during the teachers' own time after school and if it was not possible to arrange a meeting, the cycle of meetings was conducted through a process of individual visits.

3.5. Data Collection and Analysis

For the purpose of analysis, the children have been grouped by age into *infants* (5-7), *lower juniors* (8-9) and *upper juniors* (10-11). In case of any doubt surrounding the particular grouping of a child, the year of schooling was used to decide the appropriate cohort for a child.

The data were gathered using a mixture of written questions and interviews. Groups of children, of about four in number, were asked to write their answers and complete any that required drawing e.g. a drawing of what is inside your body or a drawing of four things that they do to keep healthy. Many responses were then discussed with the children in individual interviews to obtain further clarification of their meaning and the children's answers annotated by the interviewer. Additional activities were sometimes included in the interviews. For instance, in one task a set of 9 objects/drawings were presented individually to the child and the question asked "Is this .... living, once living or never living?" The child's responses were then recorded by the interviewer.

Data were gathered in two phases, an elicitation phase prior to the intervention and a further elicitation phase after the intervention. These two phases were generally separated by a period of 6-8 weeks as the intervention work was undertaken over a 'half-term' period. All the data were gathered by John Meadows, the full-time project officer and the author.

The methodology used in analysis of the data was firstly a simple categorisation of the answers and a frequency count. Some of these categorisations were based on the commonly accepted everyday meanings e.g. healthy and non-healthy foods. Other categorisations were based on an empirical approach to the data from the responses provided by children which sought to reflect their meanings

For those data where there were two or more aspects to the response i.e. the nature and function of the blood, the data were analysed using systemic networks (Bliss, Ogborn, & Monk, 1983). These networks allow for several parallel aspects of individual responses to be viewed in conjunction and present a more holistic impression of the concept that children may be using to answer elicitation questions on the same topic. Thus they preserve the subtlety and complexity of their responses, whilst providing a tool for gaining an overview of the range of responses. In addition, the categorisation system allows the number of each type of response to be enumerated and a comparison of the pre- and post-elicitation responses to be made using a chi-square test to see if there were significant changes as a consequence of the intervention.

Data were conjoined through the use of one of two devices, called a 'bra' or a 'bar' respectively, for which the symbolic representations are shown below (Fig 3.2 & Fig 3.3). Fig 3.2 shows part of the network to code children's drawings of the heart. The child either draws a heart which is too large, approximately the correct size or too small, but obviously cannot give more than one of these responses. Each of these responses is called a 'terminal' and counts can be made of the number of responses classified by each terminal.

A 'bra' is the converse in that the categories are inclusive and the response of the child may be in one or more of the categories. Hence children's responses about their knowledge of the heart may contain aspects about the location, shape, size and function. In logic terms a 'bar' is exclusive whereas a 'bra' is inclusive. Again, the number of the responses at the terminals can be counted.

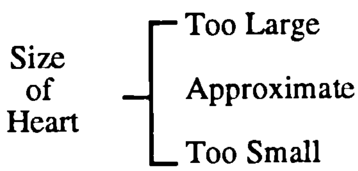


Fig 3.2 An example of a 'bar' used in systemic networks

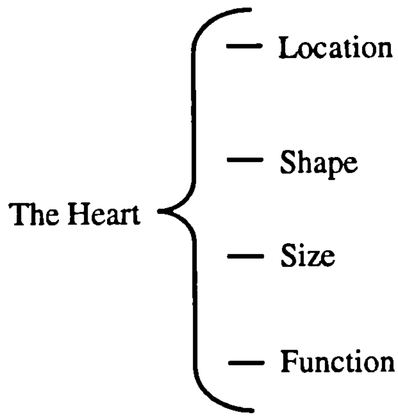


Fig 3.3: An example of a 'bra' used in systemic networks

In certain networks e.g. Fig 4.9.2.1, the following symbol is used

Fig 3.4: Recursive symbol used in network notation.

The implication is that this branch of the network is entered more than once in order to note all the features of the child's response. Thus for instance, in Fig 4.9.2.1, for a child who has given two inconsistent responses, the top half will be entered once to show one response consisting of lines from the eye to the object and again for the second response which shows lines from the object to the eye. The network is then said to be used 'recursively' and this requires some care in handling aspects of the data.

All of the networks used in this research evolved through an iterative process of examining the data, devising a network, testing the data for *completeness* i.e. that it incorporated all features of the data, and *self-consistency* i.e. that there was only one way of coding any item of data. This process was repeated till it was felt that the network adequately described at least 95% of the data. A second method of testing the validity of the network was used by asking other researchers to code a selection of the data using the provisional network to see if they could understand the terminology and to see if it is an adequate representation of their interpretation of the data. Where the network failed this test of learnability, it was reviewed and revised until it satisfied this criterion. In that sense the network was very much tested as a 'theory' or representation of the data. As Bliss et al (1983) argue, all these procedures represent a test of the network's validity.

The reliability of the data was tested by a process of seeing if an acceptable level of agreement between the author and another individual was obtained for the coding the data when using the final version of the network. In no case was the level of agreement less than 80% and generally greater than 90%.

The evolution of categories to describe the data using systemic networks also enabled other methods of analysing the data to be used where appropriate. One of the problems of using the networks is that it gives a holistic description of the data and hides individual variation and change. Therefore in chapter 4, a method is reported which uses some of the network categorisations of the data to explore the nature of changes that occurred at an individual level over the intervention period.

In Chapter 7, which explores children's understanding of astronomy, a systematic attempt was made to explore correlations and interdependences of children's concepts of the units of day, month and year using the del-coefficient. Full details of its use can be found there.

Unfortunately, it has not been possible to explore further correlations of children's understanding between different domains of scientific knowledge as during the time period over which the research was conducted, 1988-91, different schools, pupils and teachers were used.

3.7. Format of Reported Research

Chapter 4, 5, 6 and 7 report the research which forms the substance of this thesis. These chapters are a modification and synthesis of the research as already reported and published (Osborne, Black, Smith, & Meadows, 1990; Osborne, Black, Smith, & Meadows, 1991; Osborne, Wadsworth, & Black, 1992; Osborne, Wadsworth, Black, & Meadows, 1993). Each chapter contains a review of previous research in the domain and its implications for the research. This is followed by a report of the data collected with a discussion of its implications. General conclusions from the whole work are discussed in chapter 8.

4. *LIGHT: Young Children's Understanding and its Development*

4.1.1: General Introduction

Chapters 4, 5, 6 & 7 follow a standard format. In each, there is a initial discussion of previous research followed by any points about the elicitation and intervention work specific to the domain not covered in chapter 2. The bulk of the chapter though, is devoted to a discussion of the data obtained from the elicitations and intervention work. and as such, each of these chapters is an edited and revised version of work that has already been published as research reports on the SPACE project

Previous research of children's thinking in this domain has predominantly been done with children of age 9 or older. Therefore, although some of its relevance is questionable, it has been valuable for two purposes - to provide an initial interpretive framework for the data, and to provide ideas for activities and items which could be used to elicit children's thinking.

4.2. A Review of previous research into Children's understanding of Light

4.2.1 Introduction

The child's understanding of phenomena associated with light has attracted considerable interest from a number of researchers in different countries. Work has been done in France, Great Britain, New Zealand, Sweden, Switzerland, India and the USA. Predominantly this work has been done with secondary age pupils. A remarkable feature of this work is the similarity of findings reflecting a cultural and linguistic independency.

Some of the earliest research findings reported in this area are by Piaget (1974) who noted that young children make no connection between eye and object, whilst at a later stage they commonly think of vision as 'a passage from the eye to the object'. The nature of this link and association has bee studied extensively by Guesne (1978; 1985). n
The following is a summary of her and others findings.

4.2.2 Children's ideas about light

A minority of students hold the view that light is an omnipresent medium and is not identified with a particular source (Rosa,Mayer,Patrizi, & Vicentini-Missoni, 1984).

Student's holding this conception will view daylight as providing a 'sea of light' which enables vision (Guesne, 1978) The light is located in space between source and effect. Such students do not readily acknowledge that light is the result of a disturbance which propagates through space with rectilinear properties.

Guesne (1978) found that a minority of older children (13-14) would recognise the notion of light moving in a rectilinear path and use this to explain shadows. She distinguished two separate notions which she saw as part of a developmental process. Those students, generally younger (11-12) who equated light with its source, its effects or its state, and those who recognised light as a separate entity, situated in space between the source and effects that produce it. The former would often talk about light being 'in the bulbs' or 'on the ceiling' whilst the latter would talk about light not being 'able to *pass through* the paper' causing a shadow. However their conception of movement along the path was unclear and their answers suggested that light needs an impetus to maintain its motion throughout space. Stead and Osborne (1980), using a set of simple but revealing multiple choice questions, showed that the impetus notion was widely held. With faint sources, the light did not move beyond the surface of the source. It would also travel further at night. This view is supported by work done by Guesne (1978) and Andersson and Karqvsst (1983). There is little evidence in any of the work to support the view that many children commonly see light as something which propagates indefinitely through space.

Shadows are often seen as being 'reflections' of objects (Guesne, 1978). She gives several examples in which the term 'reflection' is used to explain shadow formation. However, both she and Ramadas & Driver (1989) point to the fact that the term is used loosely to describe the similarity of form i.e. that the child is merely equating the light with its effects, noting the correlation of the effects. Such children would be able to correctly predict the shape of the shadow but would not be able to predict the effect of changing the spatial relationship between source, object and screen.

Image formation by a plane mirror has also been extensively investigated (Goldberg & McDermott, 1986; Guesne, 1985; Jung, 1981). The common feature of this work is the widely and strongly held view that the image is resident on the screen or possibly just behind it. Ramadas (1989) reports a study carried out in India with a group of children, aged 14-15. A teaching sequence which was designed to challenge their ideas about the position of the image notably failed to produce any significant shift in their thinking.

4.2.3 Children's Ideas about vision

Vision is perceived as an active process in which the subject is the origin of the action. Typically a child will state

> '..Here *my eyes can go right up to the box*......It's my sight.....If it (the box) was fifteen kilometres away, I couldn't see it, because... my sight isn't strong enough...'
>
> Guesne (1978), p 188.

Guesne draws a careful distinction between this and historical parallels, notably the Pythagorean view that vision was exclusively due to an invisible fire emanating from the eyes. Children see the movement from the eyes to the object as something which is essentially abstract and this is clearly differentiated from the 'visual fire' of early theories. She found that for a significant number of children, vision is represented as a process in which the eye is sending out 'rays' which return to the head with a message or picture. Remarkably similar ideas are found in the research of Andersson and Karqvsst (1983) who looked at the understanding of light held by Swedish pupils, age 12-15. Both Guesne, and Andersson and Karrqvist (1983), found that the physicist's model is relatively rare at this age which would support Piaget's view that only children who achieve formal operations are capable of recognising that light exists as an independent entity.

Work by Crookes and Goldby (1984) revealed that some children held the view that light comes to the eye and then goes to the object. This idea is also supported by Ramadas & Driver (1989). The latter's research uses some data from the Assessment of Performance Unit in the UK to produce an extensive schema for classifying children's ideas of vision. A simpler version is used by Guesne which identified four common conceptions which she saw as stages in the progression of children's thinking about vision: the notion of ambient light which fills the space providing the light necessary to see; a source-object link which illuminates the object viewed; a source-object link illuminating the object coupled with 'active' vision, and lastly a source-object link illuminating the object coupled with receptive vision. Clearly identifiable here are the two separate links that have to be made i.e. source-object and object-eye and the joint association between the two. Children who express the ideas represented by the third step in this map of progression could be trying to reconcile the knowledge that light is needed for vision with the idea that sight is 'active'. A possible obstacle for children developing a scientific understanding, particularly for non-luminous objects, is the recognition that objects reflect or scatter light.

Both Guesne (1985) and Andersson and Karqvist (1981) have pointed to the influence of the metaphors used in language that help to reinforce the idea of vision as a process in which something emanates from the eye. We 'look daggers', 'cast our gaze, have 'piercing eyes' and 'stare at objects'. Such language clearly reflects and reinforces the intuitive understanding found in many children. In addition, comic strip figures have 'X ray vision' which can penetrate walls. Jung (1987)makes the case that common discourse is a more accurate interpretation of children's understandings. Their ideas and language are rooted in a phenomenological approach to learning based on commonsense reasoning. La Rosa et al (1985) used Jung's earlier work (1981) to define an interpretative framework for analysing data from 63 secondary school students (16-17). Their work confirmed the finding of other researchers leading them to the conclusion that 'it is difficult to find situations which challenge the predictive power' of such models.

4.3 The Research Programme

4.3.1 Introduction

Classroom work on the topic of ‘light’ took place over a relatively long period in the school year as follows.

Pilot Exploration	April-June 87
Pre-Intervention Data Collection	Sept-October 87
Intervention	Jan-Feb 88
Post-Intervention Data Collection	March 88

In exploring children’s thinking and undertaking the research work, it was important to have a map of what a preferred understanding of light would be. Such a list of learning goals was drawn up for the research.

4.3.2 Defining ‘Light’

The following list, compiled by the research team, provides a map of ideas considered an *a priori* necessity for the development of the scientist’s world view.

1. Light travels
2. Light normally travels in straight lines and can be represented by lines.
3. Light is produced by a range of sources and travels outward from the sources.
4. Many objects reflect or re-emit light as well as mirrors.
5. Primary sources of light emit light which travels long distances till it interacts with matter.

6. Vision occurs because light enters the eye from the object.

7. Shadows occur because the light is blocked by the object from travelling. A shadow should be seen as a lack of light rather than a 'reflection of' the object.

This list represents a basis or platform for the fuller understanding of the scientist. For instance, the child who thinks that vision occurs by rays emanating from the eye will not be able to understand the explanation for the formation of an image in a mirror. Many secondary teachers take such notions for granted, assuming that there is a basic simplicity about these ideas which all children have assimilated. Consequently, this list acts as an ideal reference point; a collection of ideas that children *may* develop by age 11. One of the purposes of the research would be to examine to what extent such ideas do develop in children as a result of their experiences and activities.

4.4 The Pilot Phase

The pilot exploration phase was based on interviews with a small number of children. These used a wide range of questions to explore the nature of children's understandings of the topic of light and associated concepts. In addition, drawings and answers to written questions were employed to examine how valuable and reliable such sources were for eliciting children's meanings and understanding. Full details of this phase of the work are reported in the SPACE report on light (Osborne, 1990).

The exploratory nature of this phase was necessitated by the lack of any substantial literature appropriate to this age range providing a reference point for the level and depth of children's understanding. Many of the tools devised for probing children's ideas were modifications of methods that had been used with older children. At the end of this phase, the data was examined to determine which were the most valuable lines of approach for eliciting children's ideas about this topic. This phase of the work was carried out by the research team. Ideally it would have been preferable to train the teachers involved to do more of this work. However, the lack of possible release provided little opportunity to do undertake such training. It was decided to use the available time for training the teachers for the main intervention work. Whilst the elicitation phases would be conducted by research staff with the collaboration of the classroom teachers.

The results from this preliminary work were used as a basis for refining and clarifying the elicitation questions and activities. Those activities which clearly failed to produce from children anything about their picture of light were discarded and a limited subset of questions and activities produced. For instance, questions about seeing in the dark and about glasses had failed to produce anything other than purely operational answers of the kind 'you can't see in the dark' or 'glasses help you to see'. Such answers were not revealing and these activities were omitted. The richest source of data was found to be children's drawings which provided a wealth of detail about the models they were using to explain the observed phenomena.

4.5 Elicitation

The activities for the initial elicitation were revised in the light of the experiences gained from the pilot phase by eliminating those which had not proved fruitful in providing good data about children's understanding of light. Since the pilot phase had shown that children's drawings were a particularly valuable insight into their thinking, the activities designed for the elicitation made extensive use of this technique.

Six activities were designed for use with children to explore phenomena associated with light. These were:

a. Investigating where light comes from.
b. How do bicycle reflectors work?
c. Investigations with a torch and a mirror.
d. Investigations with a torch and paper.
e. Looking at candles.
f. How do we see?

Further details of the elicitation activities can be found in Appendix 4a.

4.6. The Intervention

The design of the intervention was influenced by three factors

(a) A preliminary analysis of the data.
(b) The framework of a 'scientific' understanding reviewed earlier.
(c) The teachers' contributions and ideas.

The first elicitation phase had shown that many children had a very limited understanding of light that was rooted in observation. Very few children had a representation of light which consistently approached that of a line or rays and their models of vision were based on explanations that were mechanistic or personal e.g. 'You need light to see with', 'You see with your eyes.'

Intervention activities were selected that would require children to hypothesise about the way light travels and how they were able to see light, requiring them to use a representation of light.

It was considered unlikely that any limited intervention would achieve a major shift in children's understanding of vision. Therefore, it was felt that this phase should concentrate on providing experiences which would develop the simplest ideas in the framework; that light travels, and travels in straight lines. Activities which led to the development of these ideas would establish a solid platform for later work. In addition, it was hoped that they might lead incidentally to the growth of a more sophisticated understanding of vision which was more stable and less context-dependent.

Therefore in a meeting with the teachers, a range of activities were developed that used simple materials based around a simple piece of factual knowledge about light. The activities posed a problem to the children who were asked to devise a solution to the problem, sketching their solution first and then testing their idea. Full details can be found in Appendix 4b.

Activity 1: Bouncing Light around a table

This problem was set in the context of a simple game for the children. Children were reminded that light can be 'bounced off ' i.e. reflected from mirrors. The problem was posed as one of 'How could they make the light go round every side of the table?' A strong torch, mirrors and plasticine were provided and the children had to discuss a preliminary solution before attempting this exercise. When they had devised a possible solution, the children would work as a group and use the mirrors, held in position by the plasticine, to test their idea. The mirror angles could be adjusted easily and the light directed from one child to another.

The intention of such an exercise was that it would provide an experience which *may* develop the concept that light travels and goes in straight lines. Children would have to talk about a solution in terms of 'light going from one mirror to another' and implicitly recognising it as a medium which travels. Children's interest in performing this task was generally good though the manipulative skills required were quite demanding.

Activity 2: Investigating Shadows.

Again the intention of this activity was to develop the idea of light travelling through space in straight lines and to encourage the use and development of a method of representing light. The activities were presented as prediction exercises and children were asked to guess and predict the shapes of shadows formed by a variety of objects, to construct a method of testing their ideas and record their results afterwards. Teachers were asked to provide an opportunity for children to use their own ideas, by discussing with the group initially what caused shadows and when did we get lots of shadows. This activity was emphasised as an important process if any conceptual adjustment was to take place. No development of, or conflict with existing models, could occur unless the child was aware of his or her own ideas.

Activity 3: Passing light through boxes.
This activity made use of shoe boxes with small holes positioned on each side (Fig 4.6.1). In addition, the box had a mirror placed at one end of it. Children were asked to predict where the light would go when the torch was turned on by adding to Fig 4.6.1 and then, to repeat this process in a second situation, where the torch was directed at the mirror through the hole in the side. As an activity, they set up the box with the torch in the situations shown and tested whether the light from the torch was visible at the various holes in the box.

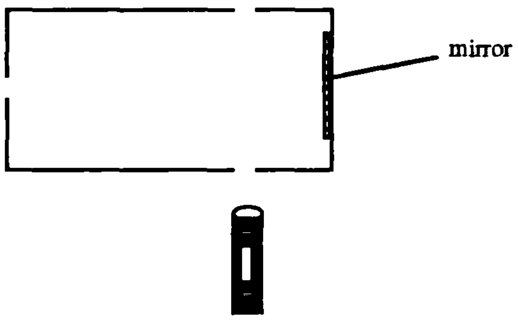


Fig 4.6.1: Diagram of apparatus used for intervention activity.

When they had completed the exercise, they were asked to draw again where they thought the light went in the box and compare their current thoughts with their previous drawings.

The intervention took place over a month and teachers were asked to try all activities with groups of children when appropriate to their normal classroom work and any others that were appropriate to the general framework (see section 2.11). Teachers received visits from one of the researchers during this phase of the work to provide support and guidance. In addition, researchers were involved in trying activities with groups of children.

4.7 The Collection and Analysis of the Data

This section gives the technical analysis of the data gathered during this study of children's understanding of light. Examination of the data identified four main areas of focus in children's ideas. These were ideas about

a. Sources of Light
b. Representations of Light

c. The nature of Vision
d. Context dependence

This data on children's ideas about light was gathered in two phases, the elicitation phase, prior to the intervention and by a second elicitation exercise - post-intervention. This produced a large collection of data for analysis which is presented and discussed here. The elicitation activities consisted of tasks that were designed to focus and orientate children's thinking on particular phenomena associated with light. Children were then asked to draw or write answers to specific questions about the instances and this provided the vast majority of the data. Some data were also collected by interview. Ideally it would have been preferable to collect much more of the data in the elicitation phase by this method, However, this limitation was compensated for in two ways. Firstly the study was limited to specific activities that the early exploratory work had shown to generate meaningful and interesting responses from children. Secondly, a substantial amount of redundancy was built into the elicitation activities in order to evaluate the consistency of the responses provided by the children.

One constraint that was imposed by circumstances relatively early in the this phase of the research was a decision to limit the study to junior age (7-11) children only. Teachers in the schools used were unwilling to involve infant children in the project at this stage till they had developed a body of experience about the methods of the project.

A report of the data collected in both phases of the elicitation is now provided.

4.8. Sources of Light

Both elicitation activities had included questions about the origin of light. In particular, the questions asked were:-

> 'Look around the room. Where do you think the light is coming from?'
>
> 'Draw pictures of all the different things that you think can give off light.'
>
> 'How does light get here?'

The wide-ranging responses provided a large body of data about sources of light and the way light travels as viewed by these children. These were summarised by using network analysis and Fig 4.8.3 shows the responses of each grouping, lower juniors and upper juniors, pre- and post-intervention. In contrast, Fig 4.8.4 shows the data summarised by i) adding the data for both groupings together pre-and then post intervention to provide a picture of overall changes for the whole cohort; and ii) adding the all lower junior responses both pre- and post intervention and likewise for the upper juniors to see if this method revealed any natural differences that existed between the two groups.

Some interesting features emerge. Firstly, nearly all pupils are aware of a wide variety of sources of light. Fig 4.8.1 and Fig 4.8.2 show typical drawings provided by children of differing ages.

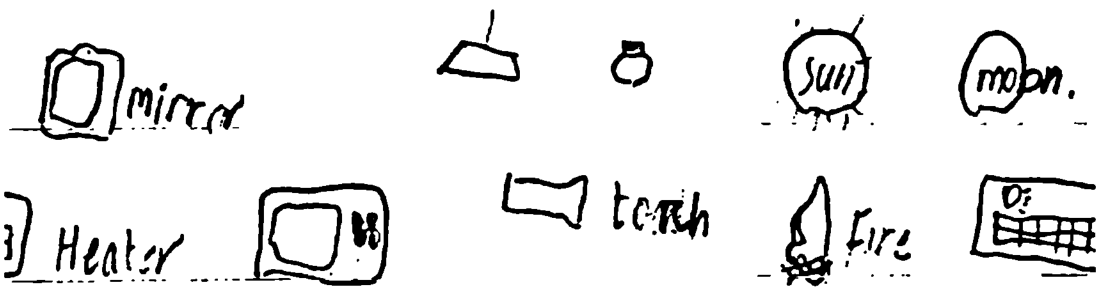


Fig 4.8.1. Child's Drawing of sources of light (Age 8)

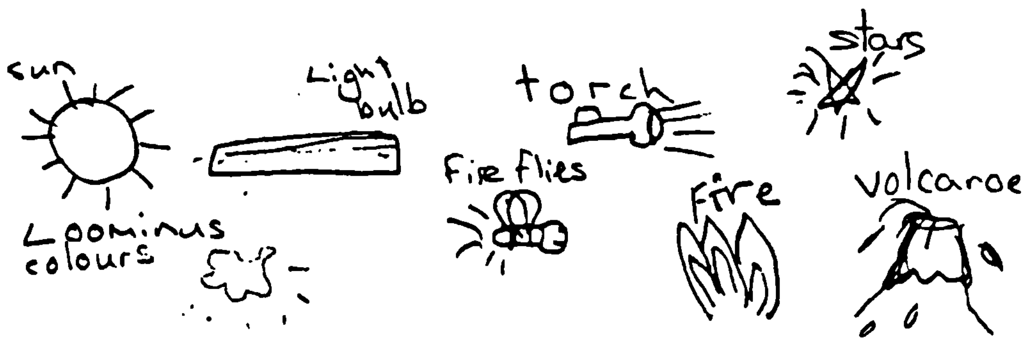
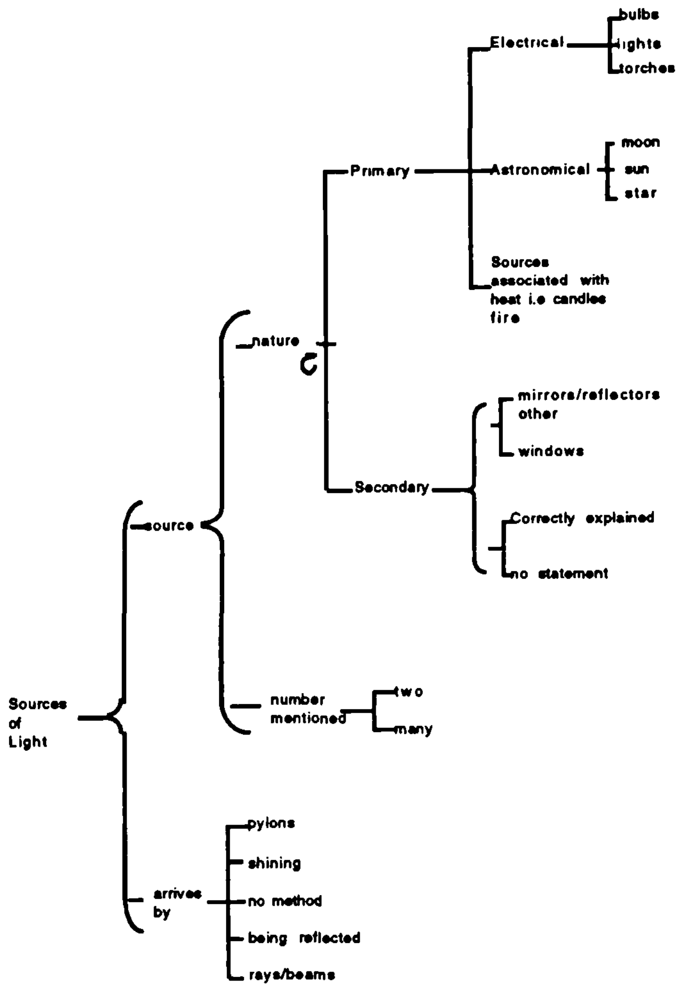


Fig 4.8.2. Child's Drawing of sources of light (Age 11)

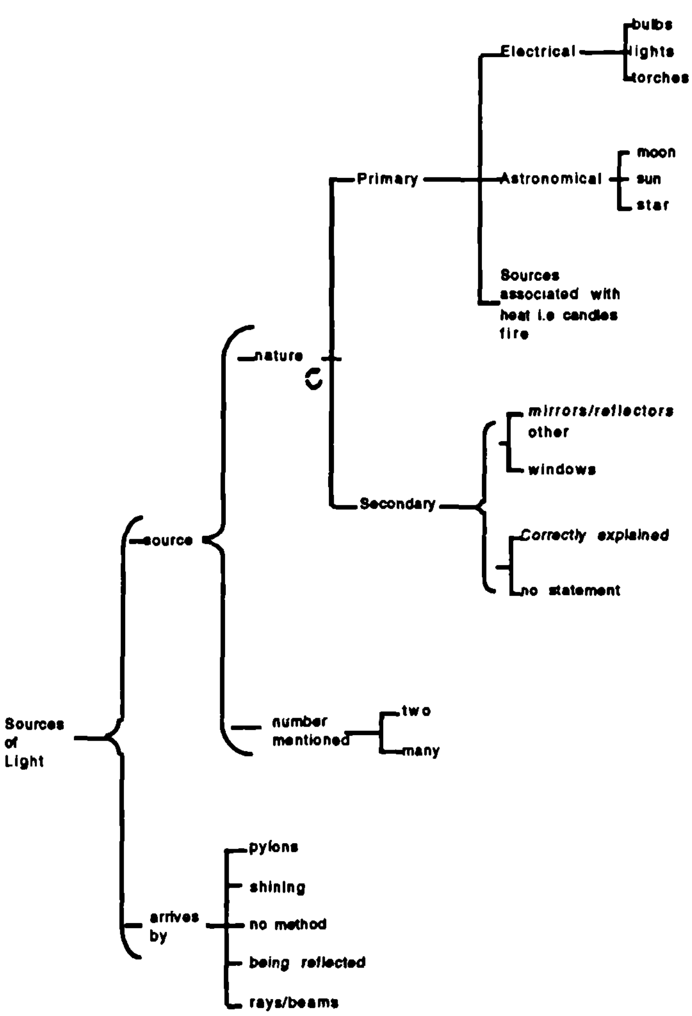
Children's drawings predominantly showed primary sources of light. Some drawings did include reflectors and windows but these were much rarer. Asked 'Where is the



	PRE-INTERVENTION		POST INTERVENTION	
	Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
bulbs	11	16	21	23
lights	19	18	17	18
torches	14	25	18	23
moon	14	9	9	10
sun	29	29	28	28
star	10	8	7	5
Sources associated with heat i.e candles fire	11	28	11	26
mirrors/reflectors other	4	8	7	3
windows	26	18	21	22
Correctly explained	7	6	7	13
no statement	23	20	21	12
two	2	1	2	-
many	29	32	29	33
pylons	3	1	1	-
shining	19	14	26	18
no method	5	10	1	7
being reflected	-	-	1	7
rays/beams	4	8	2	1

Fig 4.8.3: Network analysis for children's ideas of sources of light showing results for the intervention

light coming from in this room?', children did provide responses that show an awareness of secondary sources such as window, mirrors and the ceiling. However, only rarely did they offer an explanation of where the light for the secondary source originates i.e. 'The light is coming through the windows from the sun', and statements about secondary sources were not normally expanded. One possible explanation is that the use of the phrase 'give off' in the question (see Appendix 4a), focuses children's thinking on primary sources.



TOTALS

Pre-Intervention L. Juniors + U.Juniors n=64	Post Intervention L.Juniors + U.Juniors n=64	Pre & Post Lower Juniors n=62	Pre & Post Upper Juniors n=66
27	44	32	38
37	35	36	36
39	41	32	48
23	19	23	19
58	56	57	56
16	12	17	13
39	37	22	54
12	10	11	11
44	43	47	40
13	20	14	19
43	33	44	32
3	2	4	1
61	62	56	65
4	1	4	1
33	44	45	32
15	8	6	17
-	8	1	7
12	3	6	9

Fig 4.8.4 Network analysis for children's ideas of sources showing figures for totals.

Very few children showed less than three sources and many drew in excess of six. The other feature of their responses was that there was no marked change with age as to the number of sources or the nature of the drawings. This data suggests that the idea of a source of light, and an awareness of a wide variety of sources is a well established concept by the age of 7/8, the youngest age which this study dealt with. Perhaps this is not surprising, because, if children's understandings are based in their perceptions, then everyday life provides a wealth of observations of a range of light sources.

The second feature incorporated in the network shown in Fig 4.8.4 is a summary of the responses that children gave to the question 'How does light get here?' The most sophisticated would provide explanations of the form

'The sun beams light down onto the earth'

or show drawings of the form shown in Fig 4.8.5

Fig 4.8.5. Child's (Age 7) drawing showing 'how light gets here.'

Only a few showed clear evidence of a model of light which is travelling (Fig 4.8.6). Similarly in the research on sound, it was found that young children had no notion of sound travelling - they hear because they listen hard (Watt & Russell, 1990).

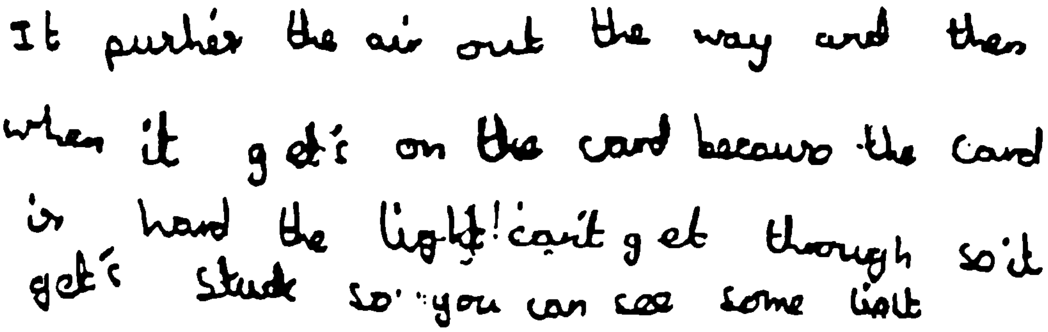


Fig 4.8.6: Child's (Age 9) written explanation for 'how light gets here.'

Interestingly, this answer reveals that this child had not yet understood the more difficult concept that not all the light stops at the card.

However, answers of this sophistication were generally rare and it was much more common to provide answers of the form, 'the sun', 'by rays' or 'it beams down'. Many children had no explanation for how the light arrived. No children offered any elaboration of these answers and no evidence was found that the scientist's abstraction of light as a ray, which propagates rectilinearly, is part of children's vocabulary and understanding over these ages.

Extracting the data from the network (Fig 4.8.3) for a summary shown in Table 4.8.1 shows clearly the predominance of primary sources.

	Pre-Intervention Lower Juniors (n=31)	*Pre-Intervention* Upper Juniors (n=33)	*Post-Intervention* Lower Juniors (n=31)	*Post-Intervention* Upper Juniors (n=33)
Number of instances primary sources shown	108	133	111	134
Mean number of primary sources shown per individual	3.5	4.0	3.6	4.0
Number of instances secondary sources shown	30	26	28	25
Mean number of secondary sources shown per individual	1.0	0.8	1.0	0.8

Table 4.8.1. Total Number of Primary and Secondary Sources indicated

These summary figures indicate there was remarkably little variation in the mean number of sources of light indicated by children before and after the intervention. In addition, the average figures show that children found it easy to indicate a reasonable number of objects which are sources of light, and that there was little difference between lower and upper juniors. Upper juniors did volunteer more sources but the distinction was small and the intervention produced no significant change.

Primary sources were mentioned by children 3-4 times more often than secondary sources. An examination of Fig 4.8.3 and Fig 4.8.4 shows that the most common source mentioned by children was the Sun, which was mentioned by a minimum of 85% for any one sample. Other common sources mentioned were torches (minimum 45% of sample) and windows (minimum 55% of sample).

Some further insights can be gained by totalling the responses from lower juniors and upper juniors pre- and post-intervention and examining the data for significant variations. Analysis of the data from this perspective provides an indication of any significant differences that occurred between these two groups *regardless of the intervention*. The network in Fig 4.8.4 shows the figures obtained by totalling the scores in this manner. The figures were tested for statistical significance of any changes by compositing the figures in two ways and using a chi-square test. Firstly by adding all the responses for both lower and upper juniors together and comparing the totals pre and post intervention. This gave a view of any changes that had occurred in the whole group; and secondly, by adding all the responses for lower juniors for both the pre and post-elicitation together and repeating this operation for the upper juniors. This provided some insight into the differences that existed between the groups anyway, regardless of the intervention. and a summary of the significant changes and differences is shown in Table 4.8.2.

	Significant change in the elicitations after the intervention by: Lower Juniors	Upper Juniors	Total	*Differences in understanding between Lower Juniors and Upper Juniors existing prior to the Intervention*
bulbs shown as sources	$p < 0.05$	-	$p < 0.01$	-
torches shown as sources	-	-	-	$p < 0.05$
heat sources	-	-	-	$p < 0.01$
no statement about secondary sources	-	($p < 0.05$)[1]	-	($p < 0.05$)
Light arrives by shining	$p < 0.05$	-	$p < 0.05$	($p < 0.01$)
No method	-	-	-	$p < 0.05$

Table 4.8.2: Statistical significance of changes in ideas about sources.

1 Figures shown in brackets represent significant *decreases*. All the others represent significant increases.

Although table 4.8.2 shows that some of the changes were significant, it is notable that there are more significant differences associated with the change in age range than the intervention. Apart from fewer upper juniors who explained the arrival of light by shining, they were all positively weighted changes towards a more elaborated model of sources and how light travels. For instance, the number of upper juniors who were able to give an explanation of the origin of light from secondary sources improved from 6 to 13 out of 33 (just failing to be significant at the .05 level). This data would therefore suggest that there is some experiential development with age, though it is important to note again that for the majority of categories in the network, ***there was no significant change***. The hypothesis suggested to explain this result is that children's ideas about sources of light are well developed and rooted in commonplace observations of light coming from a wide range of primary sources. This would account for the preponderance of primary sources mentioned. Everyday observations do not recognize secondary sources, or their nature, which would possibly explain why statements about the source of light for mirrors and windows were relatively rare in both groups.

The positive effects of the intervention were very limited. This was not surprising as the preliminary data had already shown that children were familiar with a wide range of sources and it was felt that there was little that could be done to increase their awareness in the time available. Consequently the intervention phase did not primarily address this area of understanding. It is promising that more children did provide some explanation of secondary sources and talk about light 'shining' but given the small numbers and the general approach, it is best to be sceptical about placing much emphasis on this result.

Summary: *The evidence can be summarised as follows.*

a. *Young children showed an awareness of a wide variety of sources of light. The sources shown were predominantly primary sources.*

b. *There was some evidence that older juniors have a more complex model of sources which incorporates a recognition of secondary sources of light. Most of this difference can be explained by natural developmental change rather than any effect of the intervention/*

c. *The most noticeable feature shown by the data is that there is very little change in children's understanding of sources of light as a result of this intervention.*

4.9 Representations of Light

Many of the elicitation activities called on children to use drawings to provide an explanation of what was happening in the activity or, alternatively, how they achieved a set task. These activities were:-

- showing how they were able to see a torch in a mirror;
- showing how they saw the light from a candle;

- explaining how they saw a book to their younger brother/sister;
- showing how they saw a clock on the wall.

Children were encouraged to use drawings in their explanations because this was found to be a productive method of obtaining answers from children about their ideas through a familiar mode of expression. The most notable feature of their responses was the wide variation in the representations of light used by children to show what was occurring.

Again the results obtained have been categorised using a network shown in Fig 4.9.4 & Fig 4.9.5. These summarise the main features of the representations employed by children. The dominant feature of children's work was the use of lines as a means of representing light from a relatively early age. Fig 4.9.1 shows a typical example.

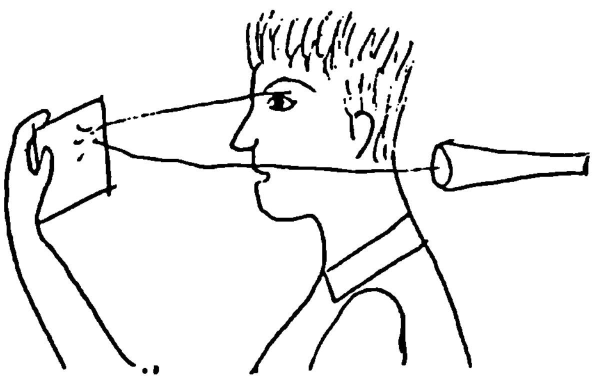


Fig 4.9.1. Child's (Age 9) drawing to show how light from torch is seen.

The second feature of many responses was the addition of arrows which showed a sense of direction (Fig 4.9.2).

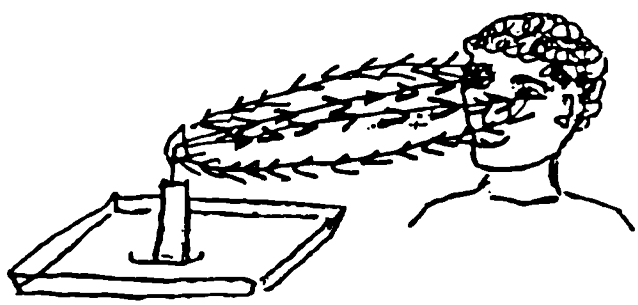


Fig 4.9.2. Child's (Age 11) drawing to show how light from candle is seen.[1]

It was also noticeable that nearly all children's work included small, short lines around sources (Fig 4.9.1 & Fig 4.9.2). The strength of this feature (87% minimum in any one sample) is perhaps surprising and it may be an *a priori* construct to developing a more sophisticated representation.

1. In this figure, the child has simply added lines to the drawing to communicate how he represents light.

However, this was not the only representation found. Others were particles where the light was shown as string of small balls or a broken line; a 'sea of light' where the light was shown by shading in the whole drawing; beams - where the light was indicated as a broad beam of light rather than a narrow line and 'blobs'. 'Blobs' was the term used by some of the children to describe a patch of light which they drew at the end of the torch or on a mirror or piece of paper as in Fig 4.9.3.

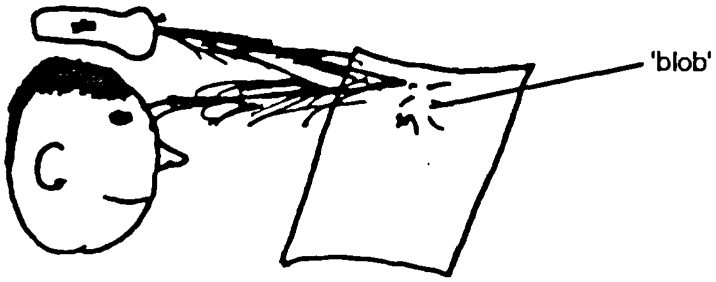


Fig 4.9.3. Child's (Age 8) drawing showing 'blob' representation of light.

The range of the representations used by children is surprising. Some representations were possibly rooted in observations of beams of light from torches and 'blobs' on paper, but the observational evidence for light consisting of lines is relatively tenuous and there is limited phenomenological experience which would give rise to such a representation.

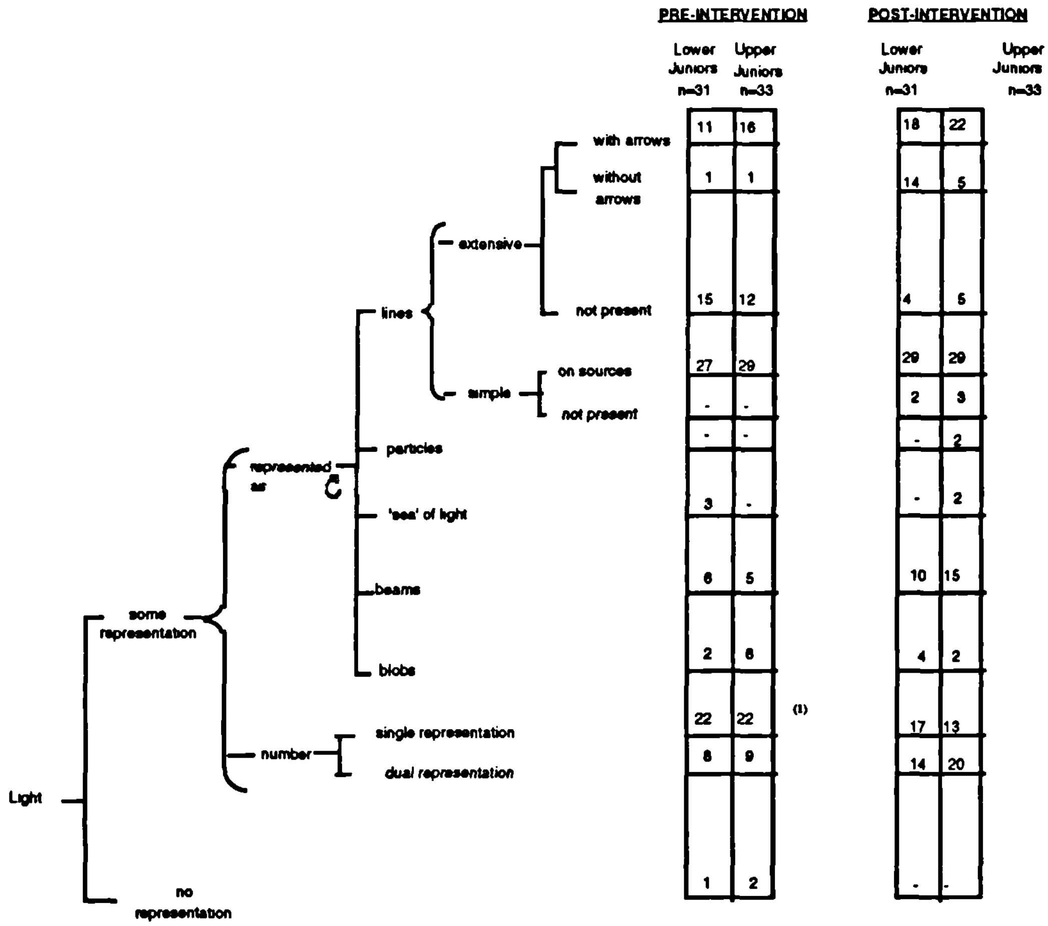
Little evidence was found here for the notion that humans and objects exist in a 'sea of light' (Guesne, 1978). However, this may reflect a failure of the elicitation or that it was problematic for children to represent such a concept with drawings.

The networks are presented in a similar manner to Fig 4.8.3 and Fig 4.8.4. There are essentially three main features to the networks that should be noted. Firstly, the intervention has produced a significant increase in the number of children using lines as a representation for light.

Table 4.9.1. shows the number using this representation by adding the first two terminals on the network together. The result shows a significant increase ($p<0.01$) in the number of children using lines to represent light for both groups and the totals. A closer examination of the network shows that the changes for lower juniors can be explained by a larger number who used lines showing no sense of direction. For upper juniors, the significant change is due to a larger number of children who showed representations of light with a sense of direction.

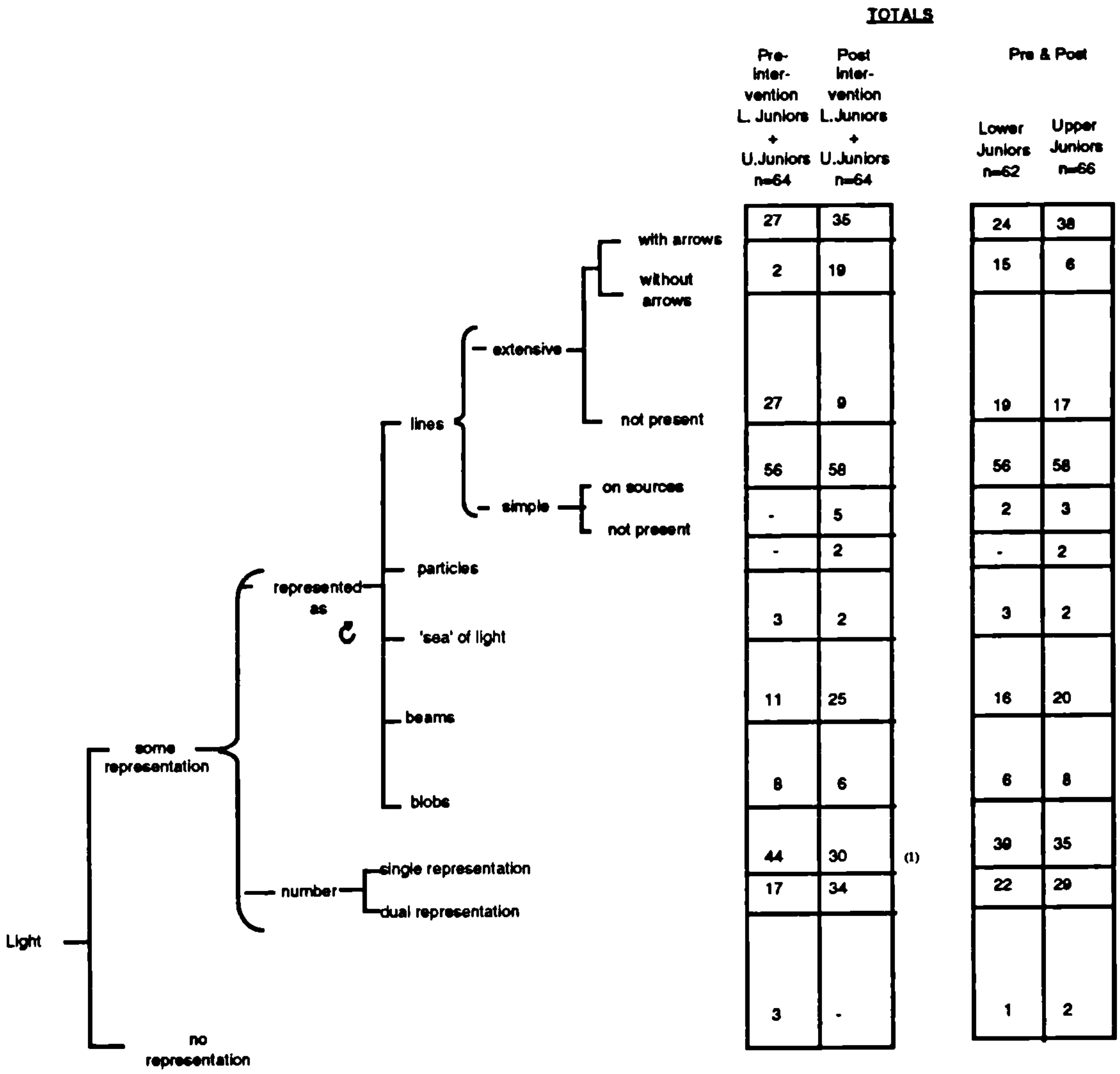
	Pre-Intervention		*Post-Intervention*	
	Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
Extensive Lines	12	17	27	27
Percentage	39%	52%	87%	82%

Table 4.9.1. Total Number of Children Using Extensive Lines to Represent Light



1 These figures show the total No of representations. In this example 22 lower juniors use a single representation and 8 use a dual representation which makes a total of 38 representations. The nature of these representations is shown by the upper half of the network.

Fig 4.9.4: Network analysis of children's representations of light



1. See the note on Fig 4.9.4

Fig 4.9.5: Network analysis of children's representations of light. Data for Totals

However, it is notable that a total for all the responses for lower juniors, and all upper juniors, pre- and post-intervention (Fig 4.9.5, column 3 and 4) shows that there was a significant difference ($p<0.05$) between these two groups in the number who used arrowed links anyway in either the pre- or post-elicitation. If the ability to represent light in the form of a directional line is considered indicative of a more sophisticated model, an implication of this result is that children of age 9-11 are developing the ability to think with such ideas anyway. However, the effect of the intervention in producing significant changes suggests that, with its emphasis on drawing and representing light, it may have contributed to the development of children's representations of light.

The second feature of the network was the increase in the number of upper juniors using beams as a means of representing light. All the other significant changes occurred for upper juniors and these are shown in Table 4.9.2.

	Lower Juniors	*Upper Juniors*	*Totals*
Representations as beams	-	$p<0.01$	-
Single representations	-	$(p<0.05)$	-
Dual representations	-	$p<0.01$	$p<0.05$

Table 4.9.2. Statistical significance of changes for representations

The increase in the number of children who used beams to represent light has no clear explanation other than that it may be based in more careful and thorough observation of car headlamps and torches. What the figures do suggest is that more children are using beams *and another* representation for light so that there is a decrease in the single representations and an increase in the dual representations of light, which is the third feature of the networks. Possibly, this is indicative of a greater fluidity in children's understanding which although richer in its repertoire, is still very context-specific, reflecting the development of a knowledge in pieces without any unifying structures as yet. Thus children's reasoning is still firmly tied to the obvious surface features of a phenomena rather than any abstracted representation of the event. Thus the two instances are seen as dissimilar and trigger different responses and knowledge of the situation. Finally it is worth noting that very few children provide no representation of light in their responses.

Summary: *The evidence can be summarised as follows.*

a. *Nearly all children will represent light around a source with short lines.*

b. *The majority of upper junior children showed light using extensive lines. The representation of light as a ray or line was seen to increase between the ages of 7 and 11. Part of this development would appear to occur with age and some of the* *development could be explained as a consequence of the specific intervention activities.*

c. *Representations of light used by upper junior children become more varied and context dependent after the intervention Significantly more children provided responses that used more than one representation of light to answer similar questions after the intervention. Part of the increase could be explained by a significant change in the number that use beams to represent light.*

d. *Nearly all children provided some representation of light.*

4.10. Young children's Understanding of the Nature of Vision

4.10.1. A qualitative overview of children's understanding of vision

Three topics in the elicitation materials addressed the nature of vision and the understanding shown by children. Pupils were asked-

(a) to show how they were able to see the light from a torch in a mirror;
(b) to explain how they saw a book to a younger brother;
(c) to add to a drawing to show how they saw a clock on the wall.

Perhaps one of the most interesting features of this research was the wealth of data it exposed about the range of ideas that children hold about the nature of vision. Essentially, this can be divided into four areas.

i. No explanation

ii. Explanations without links, e.g, written or verbal descriptions.

iii. Explanations with single links between source/object or object/eye

iv. Explanations with dual links between source, object and eye.

The data for the responses are summarised in the networks shown Fig 4.10.6.1 and Fig 4.10.6.2. A qualitative discussion is presented of the findings to illustrate the data some of the terminology used in the networks. This is followed by a statistical analysis and a discussion of the implications.

4.10.2 No explanation

For many children, particularly younger children, the process of vision appears to be non-problematic in that their drawings and explanations provide no indication of anything other than the simple act of looking. When asked to provide a drawing to show 'How you see a book?', there would be no information, other than the simple observable features (Fig 4.10.2.1)

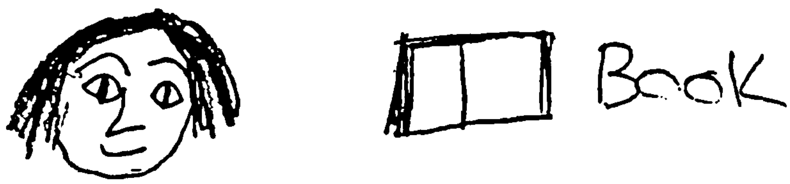


Fig 4.10.2.1 Child's (Age 11) drawing to show how we see a book.

It is possible that some children's interpretation of the question was limited to a descriptive answer as their responses were literal drawings of what a book would look like. However, there were two other questions attempting to elicit the nature of the child's understanding of vision which compensated for such interpretations of the question. Despite this opportunity, these children never gave a more extensive response. What was evident was that providing any explanation of how we perceive objects which are secondary sources of light e.g. books, was particularly difficult. Many common-sense explanations and drawings of this form shown in Fig 4.10.2.2 were observed.

Fig 4.10.2.2. Child's (Age 9) written explanation for how 'we see a book'.

Such explanations are what Biggs and Collis (1982) have termed 'prestructural' in that the response indicates a non-acceptance of the problem and lacks any understanding of a causal relationship.

4.10.3.1. Explanations without links

For some children, the explanation of how we see an object such as a book, candle or clock was not problematic. The explanation is a simple mechanistic type which recognises that your eyes are essential to vision (Fig 4.10.3.1).

Fig 4.10.3.1 Child's (Age 11) simple explanation for how we see.

No further explanation is needed and the impression given by the children was that the rationale is self-evident with a minimal or no causal link provided. Some responses of this form tie the explanation to the pupil of the eye which was seen as being involved in vision (Fig 4.10.3.2).

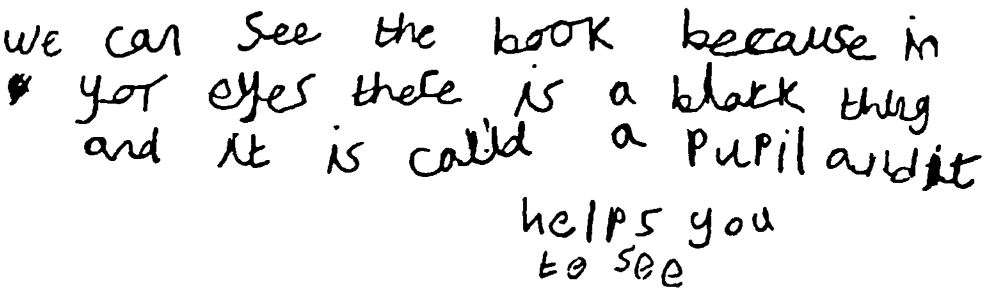


Fig 4.10.3.2: Child's (Age 8) simple written explanation for 'how we see'.

The other aspect observed in these simple explanations was a recognition that light is needed for vision (Fig 4.10.3.3).

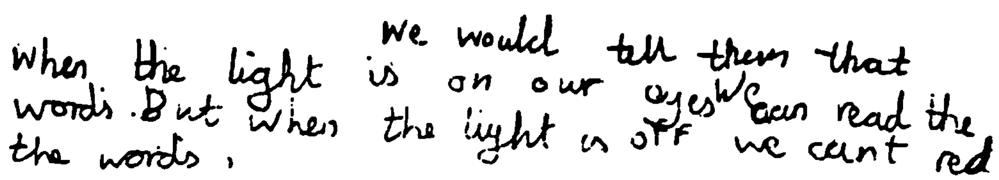


Fig 4.10.3.3 Child's (Age 10) explanation for 'how we see' recognising the need for illumination.

Such an explanation acknowledges that light is a pre-requisite for vision but fails to provide further detail of the role played by light. In the post-intervention elicitation, where children were asked to write three sentences about light, the statement that 'light is needed to see' was commonly expressed.

4.10.4.1. Explanations in terms of simple links

Many children provided explanations or drawings that showed simple links between the eye and the object (Fig 4.10.4.1) with the direction of the link shown towards the object.

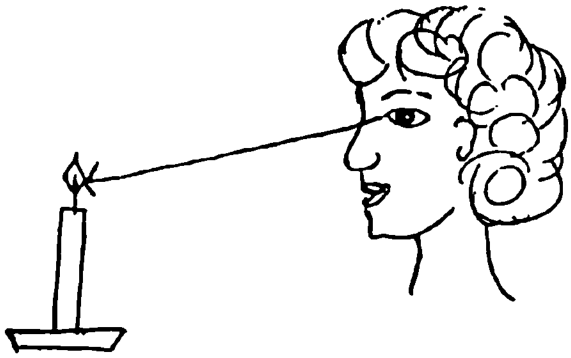


Fig 4.10.4.1. Child's (Age 10) explanation for 'how we see' showing vision as active.[1]

The large number of such responses show that these children saw vision as an active process. This is not surprising and has been reported elsewhere in the literature (Andersson, 1983; Guesne, 1978; Guesne, 1985). To look at an object, there is an action required of an individual to either move their head or eyes. The vocabulary and the metaphors of the language also imply action so that you 'give looks' i.e. 'she gave me a look like daggers' or 'his eyes shone like pearls'. However, though many answers did show a direction, there were also answers which merely recognised the link and did not show any direction (Fig 4.10.4.2).

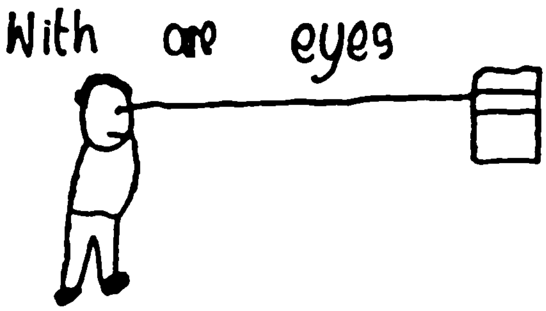


Fig 4.10.4.2 Child's (Age 8) drawing to explain how 'we see the book' using a single link

The majority of such answers showed a representation for vision using lines. However, a few indicated the link in terms of particles (Fig 4.10.4.3). There was no evidence that this reflects a view of light but it did show a different conception of the link between eye and object consistent with a particle interpretation.

1. In this figure, the child has simply added lines to the drawing to communicate how he sees the object.

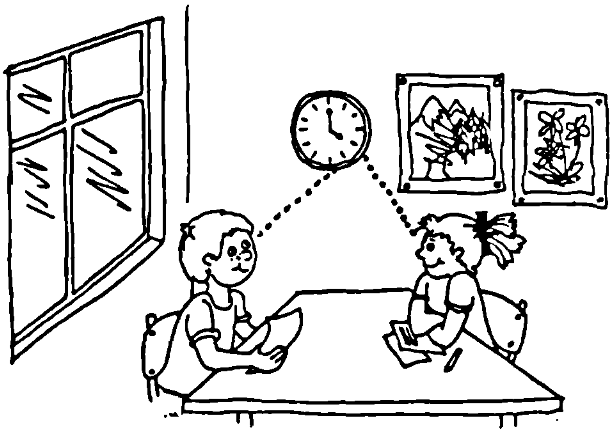


Fig 4.10.4.3. Child's (Age 10) drawing to show 'how we see' using a particle representation of light.[1]

Single links directed towards the eye are comparatively rare (Fig 4.10.4.4) which reflects the fact that only a very small minority of children had a model of vision which corresponds with the scientist's view.

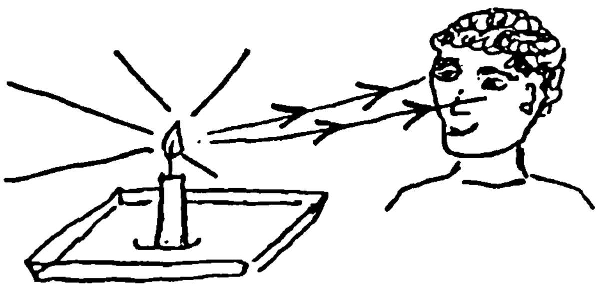


Fig 4.10.4.4 Child's (Age 10) drawing to explain 'how we see' showing representation consistent with scientific explanation.[1]

Even then in nearly all instances where the scientific explanation was given, the source was always primary source of light. Such children generally reverted to a model of 'active' vision for their drawings of how we see a book.

4.10.5 Explanations with Dual links

A small but significant number of children recognised the need to show a source-object and object-eye link to explain vision. Identifying that 'light is necessary to see' and that 'we need our eyes to see with', they showed these two factors in a variety of forms. Biggs and Collis (1982) would argue that such ideas are multistructural in that they link two ideas. The simplest was that which shows the dual link with no direction (Fig 4.10.5.1a), and with direction, Fig 4.10.5.1b.

1. In this figure, the child has simply added lines to the drawing to communicate how he sees the object.

The interesting feature of these figures is that it also shows an attempt to reconcile these two ideas with a process of active vision. Light goes (presumably) to the eye and then to the mirror. However, nearly all dual representations showed a direction as well.

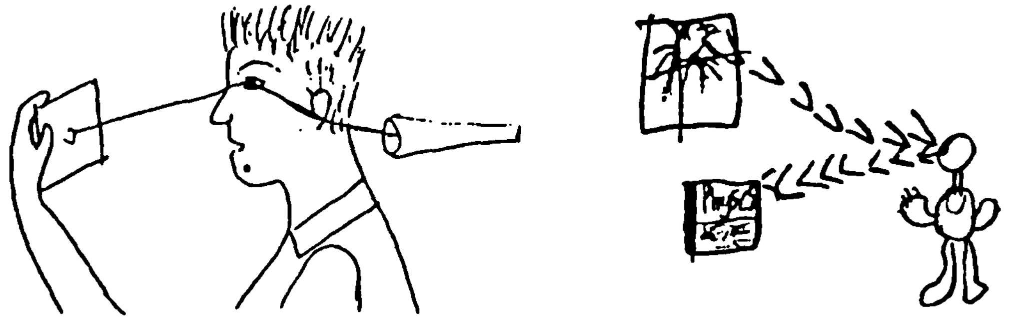


Fig 4.10.5.1a and Fig 4.10.5.1b. Children's (Age 11 and 10) explanations of how we see an object with eye-object and source-eye link shown.

The most common form of dual representation was one which showed the dual links both directed toward the object (Fig 4.10.5.2).

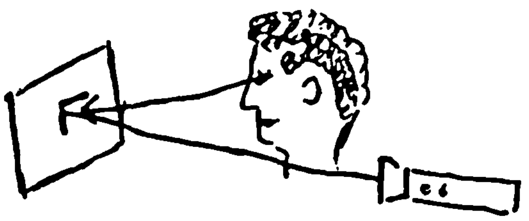


Fig 4.10.5.2 Child's (Age 10) explanation of how we see an object with eye-object and source-object link shown, both directed to object.[1]

This representation is a logical expression for children who believe that light 'gets stuck' once it reaches the object and fits with the conception of vision as being 'active'. Here, this term is used to describe children who described and drew vision in terms of lines or rays emanating from the eye. Such a representation is clearly shown in Fig 4.10.5.3 Even though the object viewed is a primary source, children's diagrams still showed a representation of 'active vision'.

However, some diagrams explaining how the light is viewed in a mirror, reveal that 'active vision' is a persistent concept which leads to representations of vision which contradict a simple observation that the torch is emitting light.

1. In this figure, the child has simply added lines to the drawing to communicate how he sees the object.

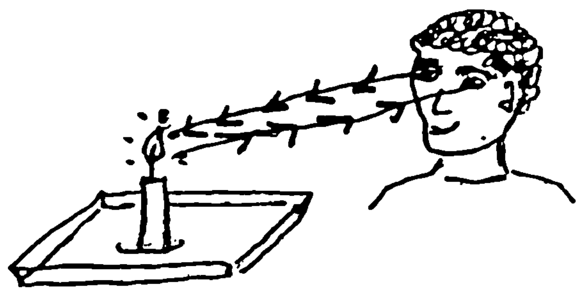


Fig 4.10.5.3 **Child's (Age 7) explanation showing dual links with 'active' vision.**[1]

Fig 4.10.5.4 shows an extension of active vision to the torch and an attempt to reconcile it with the emission of light from the torch. Lines are drawn to the mirror and then onto the torch but there is also a line from the torch towards the mirror.

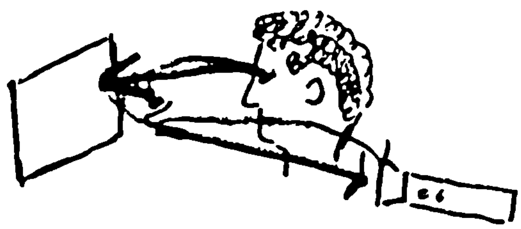


Fig 4.10.5.4 **Child's (Age 9) attempt to reconcile concept of 'active' vision with torch as a primary source of light.**[1]

Finally, there were a few children who showed a representation consistent with the scientific view (Fig 4.10.5.5). Such children were a small minority but there was some evidence that the numbers increased with age.

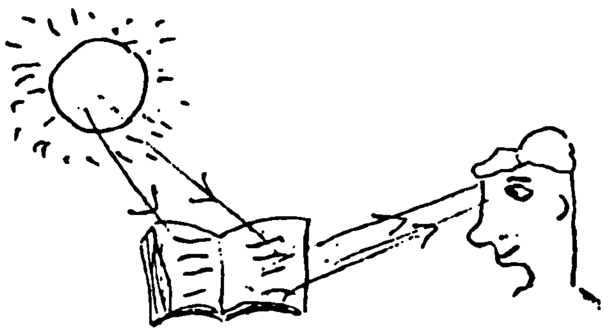


Fig 4.10.5.5. **Child's (Age 10) drawing to explain vision consistent with the scientific explanation.**

Such examples to explain how we see the book were comparatively rare and there were many more examples of a scientific representation for the torch and mirror (Fig 4.10.5.6). The simplest explanation for this would be that observations in the context of the torch and the mirror support the idea that light passes from the source to the

1. In this figure, the child has simply added lines to the drawing to communicate how he sees the object.

mirror to the eye, as it is possible to see the light 'bouncing off' the mirror onto the face. However, there is no evidence to support such an idea with a secondary source of light such as a book.

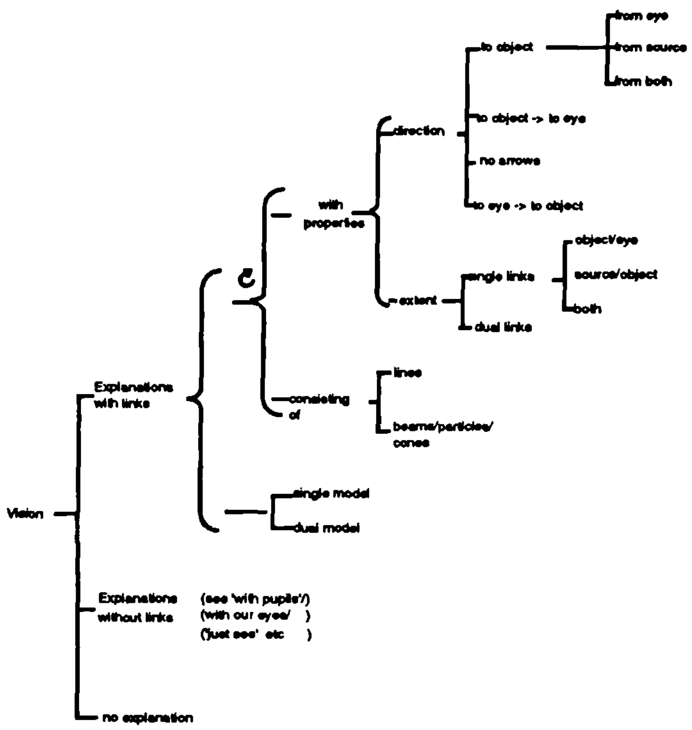
Fig 4.10.5.6 Child's (Age 11) drawing for how we see a primary source consistent with the scientific explanation.[1]

4.10.6 The Total Data

The data for all the responses were analysed and summarised in the networks shown in Fig 4.10.6.1 and Fig 4.10.6.2. Overall these show that children of all ages produced a range of responses that used links between that used links between the eye and the object and that many incorporated the sense of direction.

Table 4.10.6.1 shows a summary of the main features of the responses showing the total numbers who used a link and the numbers of those that were single or dual links. These data show a significant increase ($p<.01$) in the total number of both upper and lower juniors who show a link between eye and object though most of this change is due to an increase in the number of lower juniors using such a link. The other noticeable feature of table 4.10.6.1 is the decline in the number of responses from upper juniors to explain vision using single links between *the eye* and *object*. Single link responses dropped from 25 out of a total of 27 responses showing links, to 24 out of 44 which is significant ($p < 0.01$). This was accompanied by a significant increase in responses from upper juniors using dual links which showed an increase from 2 responses using dual links to 20 out of 44 responses ($p <0.01$) using such a representation.

1. In this figure, the child has simply added lines to the drawing to communicate how he sees the object.



PRE-INTERVENTION		POST INTERVENTION	
Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
12	16	11	13
-	-	-	1
-	-	1	5
3	3	-	8
5	7	13	7
-	1	3	10
14	25	23	18
-	-	-	1
-	-	-	5
6	2	5	20
18	24	24	40
2	3	4	4
12	21	28	22
4	3	-	11
4	3	1	-
11	6	2	-

Notes

1 The network is best understood by examining the figures for 'single' and 'dual' models. i.e for Lower juniors prior to the intervention, there were 12 single model responses (with links) and 4 dual model responses, where the child used one representation in one context and another in the other context, thus making a total of 20 responses in all. The upper half of the network shows what form these responses took.

Figure 4.10.6.1. Network Analysis of children's responses to questions about the Nature of Seeing.

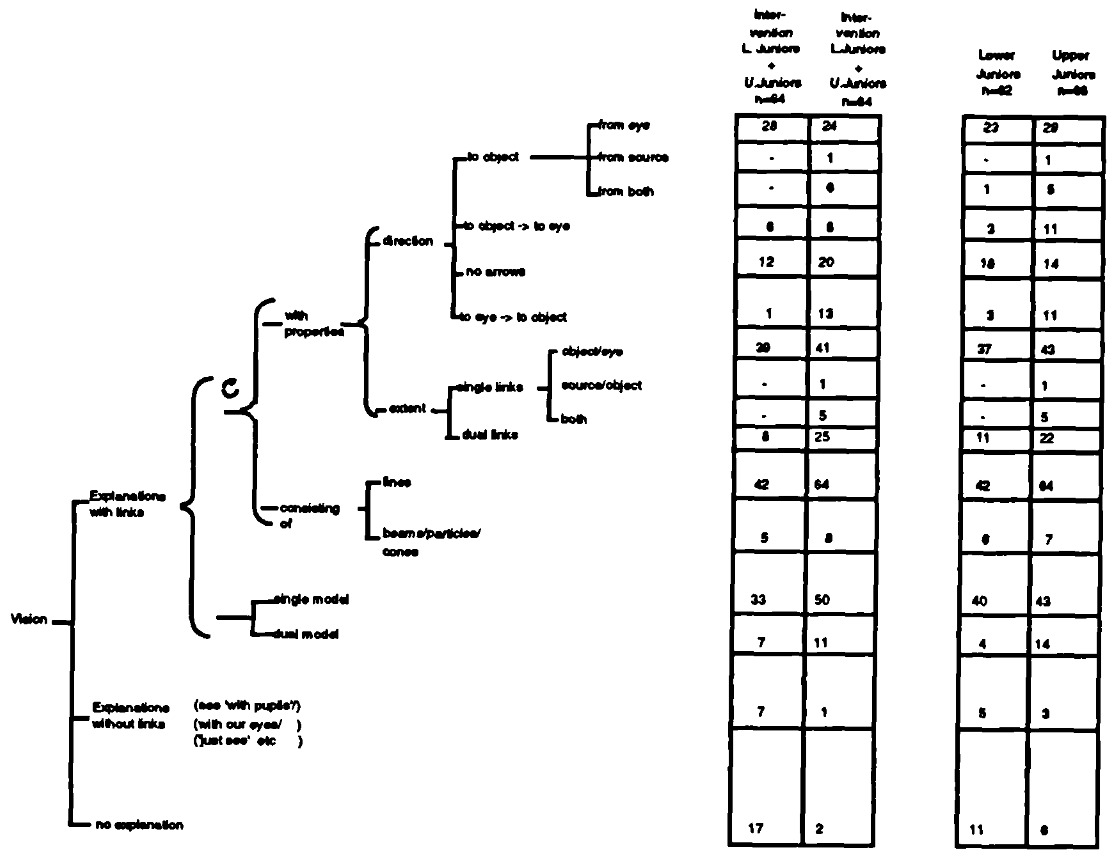


Fig 4.10.6.2. Network Analysis of Children's responses about Vision showing data for total figures.

	Pre-Intervention Lower Juniors (n=31)	Upper Juniors (n=33)	*Post-Intervention* Lower Juniors (n=31)	Upper Juniors (n=33)
No. of Responses showing link between eye and object.	20	27	28	44
No. of responses showing single links	14	25	23	24
Responses showing dual links	6	2	5	20

Table 4.10.6.1. Analysis of responses obtained which show links between eye and object

Table 4.10.6.2 shows that for those that showed a link between eye and object, the majority of children at all ages incorporated a sense of direction into their response about vision, even if incorrect. None of these changes were significant.

	Pre-Intervention		*Post-Intervention*	
	Lower Juniors (n=31)	Upper Juniors (n=33)	Lower Juniors (n=31)	Upper Juniors (n=33)
Arrowed link (%)	75%	69%	54%	84%

Table 4.10.6.2. Percentage of responses showing the sense of direction of vision.

Another noteworthy point is that there was a small minority of children in the lower juniors (15%) who were able to provide responses in terms of accepted scientific theories of vision by indicating that the light goes to the object and then to the eye. However, it would appear that such thinking was not robust as the post intervention data showed that no lower junior children had this model. Lower juniors also showed a large minority (35%) of children who provided no explanation for vision.

One weakness of the network is a failure to show children who indicated in writing in one context that vision occurs 'with our eyes' or that we 'just see the book' in addition to providing a drawing as another response. The number of such responses was counted separately and shown in Table 4.10.6.3.

	Pre-Intervention		*Post-Intervention*	
	Lower Juniors (n=31)	Upper Juniors (n=33)	Lower Juniors (n=31)	Upper Juniors (n=33)
Written response (%)	29%	24%	55%	24%

Table 4.10.6.3. Percentage of children providing additional written responses to explain vision.

The change for lower juniors was just significant ($p<0.05$) but there is no evidence to explain why this change occurred. The data indicates that there are a number of children who view vision in certain contexts as being essentially non-problematic.

Seeing is just something which happens and you see with your eyes. However, the networks show that there is a very small number of children who use this response solely. For the lower juniors, there was also a minority who offered no meaningful response to explain vision.

An analysis of the responses which showed statistically significant changes is summarised in Table 4.10.6.4. In the network (Fig 4.10.6.1) it is possible for a child to appear in any one of the upper terminals twice, if their response differs from one context to another. Therefore, the significance of any changes has been evaluated by considering the change in the total number of responses of any one type in relation to the total number of responses overall. For instance the number of responses from upper juniors, which show vision in terms of a single link to the object from the eye, decreases from 16 out of 27 total responses to 13 out of 44 responses.

Table 4.10.6.4 shows that the majority of changes have occurred for the upper juniors. These can be summarised as a decrease in the number of children using responses which showed a link from the eye *to the object*; a decrease in single links; a decrease in responses without links and a decrease in responses which provided no explanation. This was coupled with an increase in the number that showed an explanation with dual links and used context-dependent models to explain vision. However, the latter is not accounted for by an increase in the number of children using scientific models of vision, but by a growth in the number of children using explanations that show the light going to the eye and then to the object. This result suggests that more children were aware that 'light is necessary for vision' and 'eyes are needed to see' and were attempting to show both features and construct a hypothesis that would accommodate both.

Rowell and Dawson (1983) have argued that when confronted with evidence which conflicts with their existing ideas, children will often construct auxiliary hypotheses to explain the result, rather than change their core ontological commitments. This data may well reflect such a practice.

Part of the increase in the use of dual models can be explained by the significant change in the overall differences between lower and upper juniors. This suggests that part of the observed change in the use of dual models can explained by development which occurs with age. The only other significant difference between the lower junior and the upper junior cohort was that there were fewer of the latter who showed no arrows on their drawings.

	Significant changes in pupil responses between pre- and post-elicitation Lower Juniors	Upper Juniors	Total	*Overall differences between Lower and Upper Juniors*
Light shown to object from eye	-	(p<0.01)[1]	(p<0.01)	-
No arrows shown[2]	-	-	-	(p<0.05)
Light shown to eye to object	-	p<0.05	p<0.01	-
Single links shown object-eye	p<0.05	(p<0.01)	(p<0.01)	-
Dual links	-	p<0.01	p<0.05	-
Single models of vision	p<0.01	-	p<0.01	-
Dual models of vision (context-dependency)	-	p<0.05	-	p<0.05
Explanations without links	-	(p<0.05)	(p<0.05)	-
No explanation	(p<0.05)	(p<0.05)	(p<0.01)	-

Table 4.10.6.4 Statistical significance of changes in children's ideas about vision.

[1] Changes representing decreases are shown in brackets

[2] Features shown in italics are considered to be indicative of a change to the scientific world view. Other features can only be considered an improvement by a process of comparing the post-elicitation response with the pre-elicitation response for the individual the child.

The increase in context-specific responses would support the hypothesis that children's ideas are fragmented and related to specific instance, and that their ideas are fluid and pliant which has been mentioned elsewhere.

The lower junior children show very few changes. The principal change is an increase in the number of children who used a single representation. This could be explained by the significant decrease in the number of children who provide no meaningful response which suggests that these children are now showing at least one explanation for vision of greater complexity than none at all.

Finally, the observed changes are somewhat surprising as the intervention avoided directly addressing this idea of vision. It is possible that the children placed a different emphasis on the activities to that intended. Children are egocentric and the natural explanation of phenomena may highlight the individual as an active agent resulting in children thinking that something emanates from the eye. However, there was no evidence which provided the extra insight into their thinking needed to explore this issue.

In summary, it is clear that the intervention has had more effect on children's development for the upper juniors than lower juniors. This is a similar conclusion to that drawn from looking at the representations for light. The inference is that such work has possibly more value if tackled at a later stage in a junior child's development.

Summary: *The evidence can be summarised as follows.*

a. *More than half the children provided responses which indicate a link between eye and object and the majority of these responses incorporate a sense of direction.*

b. *A sizeable proportion of lower junior children (35%) provided responses which show no explanation of vision and indicate that the idea is non-problematic for them.*

c. *The main effect of the intervention work was on upper junior children who provided more responses which showed increased use of dual links i.e. eye-object and object-source. This was accompanied by an increase in the number of dual models reflecting an increase in the context dependence of responses. The implication is that such work is more appropriate to children in the 9-11 age range.*

d. *The only significant effect of the intervention for lower junior children was to increase the number of responses showing single links between object and eye and decrease those showing responses which provided no explanation.*

4.11 Context dependence of responses.

The other major feature of the answers and drawings provided by children was the context dependence of their answers. The explanation provided for vision by one child would vary from one question to another within a remarkably short time without any recognition of the of the contradictions that this might raises for an adult. There are several possible explanations for this. The simplest would be to say that children saw these situations as instances of different phenomena. Viewing a light source shown in Fig 4.11.1.a. is very different from a book shown in Fig 4.11.1.b. Consequently the responses provided are different and non-problematic for the child. Similarly Fig 4.11.2.a. could be considered an instance of 'reflection' whilst Fig 4.11.2.b. an explanation of 'vision'.

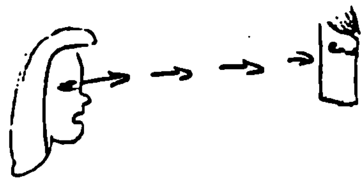
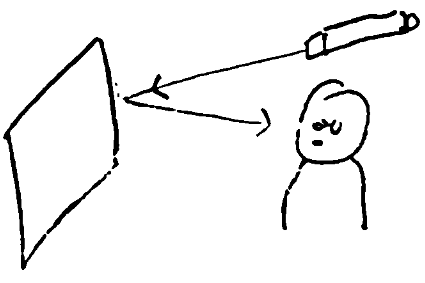


Fig 4.11.1.a[1] **Fig 4.11.1.b**
Two responses to 'how we see by the same child (Age 11)

However, both pairs of responses were generated in response to questions about 'How we see'. It is interesting that this child recognised that the candle emitting light is a primary source, which enters the eye whilst with secondary sources, she fell back on the view that vision is active. This would imply that it is impossible for children to develop a scientific view of vision until they are aware that objects such as books are capable of scattering light.



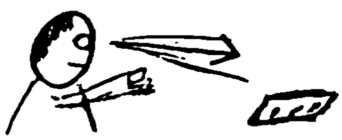
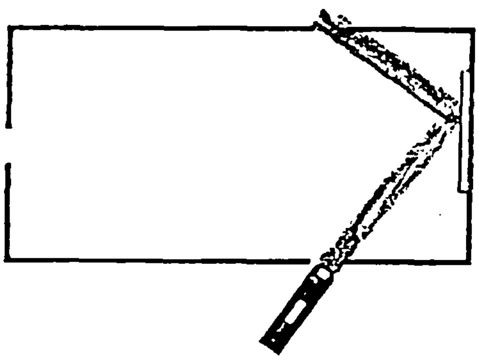


Fig 4.11.2.a **Fig 4.11.2.b**
Two responses to 'how we see by the same child (Age 9)

1. In this figure, the child has simply added lines to the drawing to communicate how he sees the object.

Clearly with a luminous source the light comes to the eye but when the source scatters light, the response shows an interpretation that used an explanation of vision as 'active'.

Similar examples can be found for the representations that children use in their drawings. Fig 4.11.3.a. shows light represented as a beam and yet later, on the same occasion, this child used a line to represent light (Fig 4.11.3.b.).



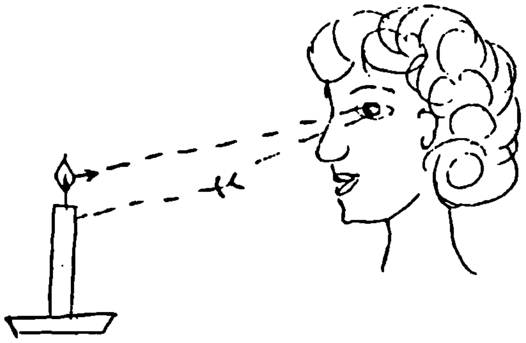


Fig 4.11.3.a[1] **Fig 4.11.3.b[1]**
Two different representations of light by the same child (Age 10)

The previous examples show that children were using models which are specific to their observations within a particular context. Torches do appear to emit light in beams so the light was drawn as a beam whilst candles do not.

Context dependent responses were observed more often in older children as very rarely had younger children developed more sophisticated models of vision whose elaboration would reveal inconsistencies. A possible explanation is that children's ideas are fluid and lack generalisability, yet are evolving as they get older to incorporate a wider range of observable features which are context dependent. More sophisticated attempts to explain vision would show dual links with a connection between object-eye and source-object which reverted to only one of these links in another response.

For the purpose of this study, we have used the notion of 'context dependence' to describe the responses of children which show different representations of light, or different mechanisms of vision *within the same elicitation i.e.,* for different items in different contexts on the same occasion. Such a position is distinct from those who would argue that the responses are merely inconsistent in that it implicitly recognises that separate responses are triggered by different stimuli and that there is a relationship between the knowledge and its stimulus. Throughout the study, such an aspect was a noticeable feature about the responses obtained from children and Table 4.11.1

1. In this figure, the child has simply added lines to the drawing to communicate how he sees the object.

summarises the data from the network showing the percentage of children who gave such responses.

	Pre-Intervention		*Post-Intervention*	
	Lower Juniors n=31	Upper Juniors n=33	Lower Juniors n=31	Upper Juniors n=33
For representations of light	25%	27%	45%	60%
For explanations of vision	13%	9%	0%	33%

Table 4.11.1. Percentage of children providing responses which show more than one model and which are inconsistent.

The changes for upper juniors were significant ($p<0.01$) and showed an increase in the use of context dependent models. Ideally science education should try and facilitate the construction of robust understandings that are generalisable. This was clearly not the case here and it is possible that such a period may be the inevitable precursor of the development of ideas which are more permanent and closer to a scientific understanding.

There are various alternative explanations for such behaviour. A Piagetian perspective (Inhelder & Piaget, 1958) would be that all these children were exhibiting early or late concrete thinking which is essentially tied to the observable features of such phenomena. Consequently, the children do not perceive any inconsistency in the different representations which would be apparent to a formal thinker. For them, there simply was no conflict. However, it may simply be a period of trying a new idea whilst clinging to an old interpretation - indeed, perhaps an essential stage in the development of children's thinking.

The data show that there are the following possible steps in a child's understanding of vision.

1. No explanation
2. Consistent wrong explanation
3. Inconsistent wrong explanation
4. Wrong and scientific explanation applied depending on the context
5. Scientific explanation applied consistently.

For Lower Juniors, the data in Figure 4.10.6.1 would indicate that the main effect of the intervention has been to move the children from stage 1 to stage 2, and for upper juniors from stage 3 to stage 4.

Summary: a. *Many children's responses to questions about their understanding of light showed different answers in different contexts.*

4.12. Individual changes in Children's Thinking.

4.12.1. Methodology

The other method for examining change is to look at what has happened to individuals. The networks provide a summary of the whole cohort, but are poor at providing insight into any of the changes that occurred for individual children. Such an analysis is important to obtain a picture of how the changes observed in the network arose. Consequently, it was necessary to develop a method of analysis that would provide some insight into any individual change.

The chosen method was based on the use of definable features of children's understanding of light which had emerged from conducting the analysis for the networks. A child's representations of light can be classified into groupings which can be said to be a) No representations, b) simple links with lines or beams, c) dual links and d) 'blobs'. Similarly an examination of the direction indicated for light can be grouped into a) no direction, b) sense of direction indicated and c) accurate sense of direction. Data for changes in children's representations of light are shown in Figure 4.12.2.1 and 4.12.2.2 whilst Figure 4.12.3.3 and 4.12.3.4 show the data for changes in their ideas about vision. The large number of questions for each topic provided a large data sample for the size of the group.

In the figures, aspects of children's understanding are enclosed in ellipses and the arrows show counts for the number of individuals who have changed their representation of light (Figure 4.12.2.1 and 4.12.2.2) between the elicitation activities, pre- and post-intervention for the *same question*. The numbers in boxes within the ellipses, show the counts for those children who did not change the representation that they used.

The figures shown are summaries for three questions in the elicitation activities and tables for each question are provided later. The figures can be summarised by grouping into three categories; (i) those which show no change; (ii) those which show a change to a view which shows a more complex representation of light (or vision) and explanation for vision; that is, one which is considered to have more of the features of a scientific representation; (iii) those which show a less sophisticated representation. It is clear from these charts that as well developing their understanding, some children go 'backwards' i.e. away from a scientific view in their understanding. Whether this is simply because the ideas they hold are simply inconsistent and unstable or whether it represent a genuine regression remains an open question.

4.12.2. Individual Changes in Representations

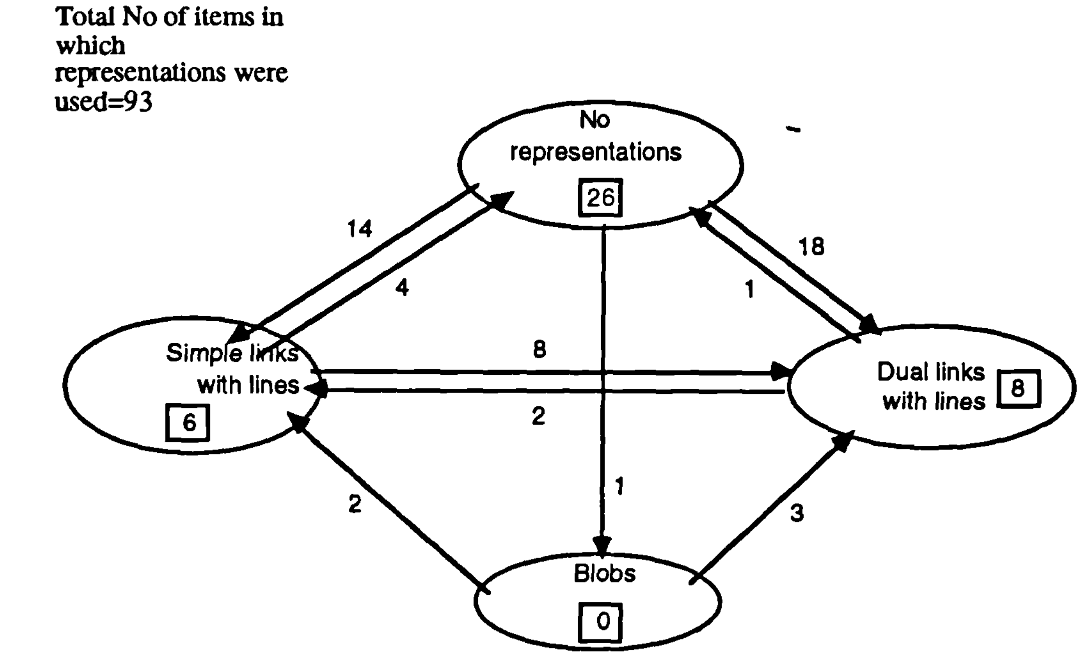
The data for individual changes in their use of representations of light are shown in Figure 4.12.2.1 and Figure 4.12.2.2. The data in these charts can be summarised in tabular form

		No Change	*Changes to more features of a scientific Model*	*Changes to fewer features of a scientific model*
UPPER JUNIORS	Representations	40	46	7
(n=93)	Direction	58	31	4
LOWER JUNIORS	Representations	65	22	3
(n=90)	Directions	76	8	6

Table 4.12.2.1. Summary figures for changes in children's representations of light.

An examination of the figures in Table 4.12.2.1 shows that more positive changes have occurred for the upper juniors than the lower juniors. This is confirmed by a chi-squared test which shows that there was a significant difference ($p<0.01$) in the pattern of figures for both representations of light, and its direction of travel between upper and lower juniors. This corroborates the analysis of the networks which showed that more change was occurring for the upper juniors than the lower juniors. A breakdown of the response for individual items shows that the main contribution to this difference was

Fig 4.12.2.1. Conceptual Map of Changes in Children's Representations of Light (Lower Juniors)



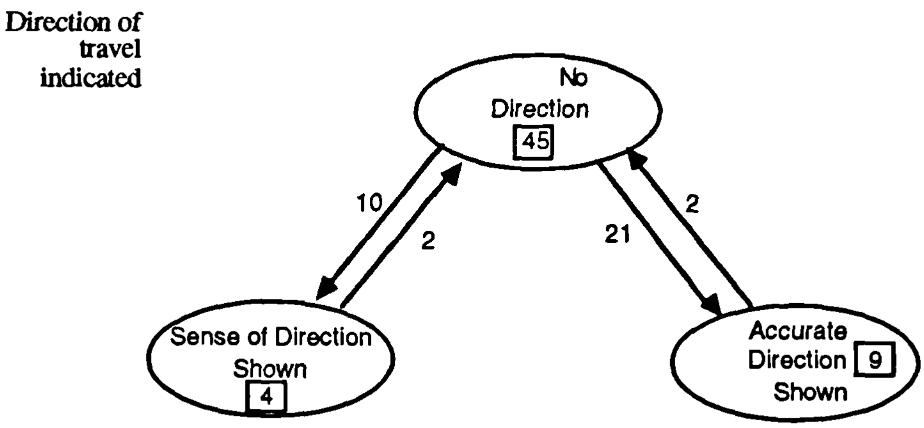


Fig 4.12.2.2. Map of changes in Children's Representation of Light (Upper Juniors)

provided by improvements in the responses of upper junior children's. This would support the notion that it was only upper junior children who are more likely to develop a model of light which is applicable to situations where the source of light is not evident.

The other feature of this analysis is that there were many more children showing no sense of direction i.e. no arrows in their drawings of light, both before and after the intervention, compared to those that showed no representation of light. This merely shows that children are often prepared to draw links without indicating a sense of direction. In the case of beams or particle representations, directions were only very rarely indicated.

More insight into the changes is provided by looking at the responses to particular questions using this method of analysis. The figures for the overall results are shown in Table 4.12.2.2 & 4.12.2.3.

Question	*Candle*	*Book*	*Clock*
UPPER JUNIORS	10(34)[1]	17(30)	13(29)
Direction indicated	16	22	20
LOWER JUNIORS	13(30)	29(30)	23(30)
Direction Indicated	21	29	26

1 Figures in brackets show the number of responses on this item.

Table 4.12.2.2. Number of children who showed *no change* on questions eliciting representations of light

These figures show some more insight into the nature of the changes that have occurred. Changes in response to the question asking children to draw how they see the candle were similar for both groups. For the lower juniors, there was very little improvement in their responses to the questions asking them to draw and explain how we see a book and a clock, both secondary sources of light. There has been some change for the upper juniors and this change in the responses of the upper juniors to these questions which is significantly different from that for the lower juniors.

These data would suggest that the intervention has had little success in helping children of lower junior age construct a model which represents the role played by light in seeing secondary sources. More success has been achieved in improving their explanations for how we see primary sources where the origin of the light is more tangible. This is confirmed by the figures in Table 4.12.2.3 which shows very few lower junior children have moved to a more sophisticated understanding of light for secondary sources.

Question	*Candle*	*Book*	*Clock*
UPPER JUNIORS	21(34)	13(30)	12(29)
Direction indicated	14	8	9
LOWER JUNIORS	16(30)	1(30)	5(30)
Direction Indicated	3	1	4

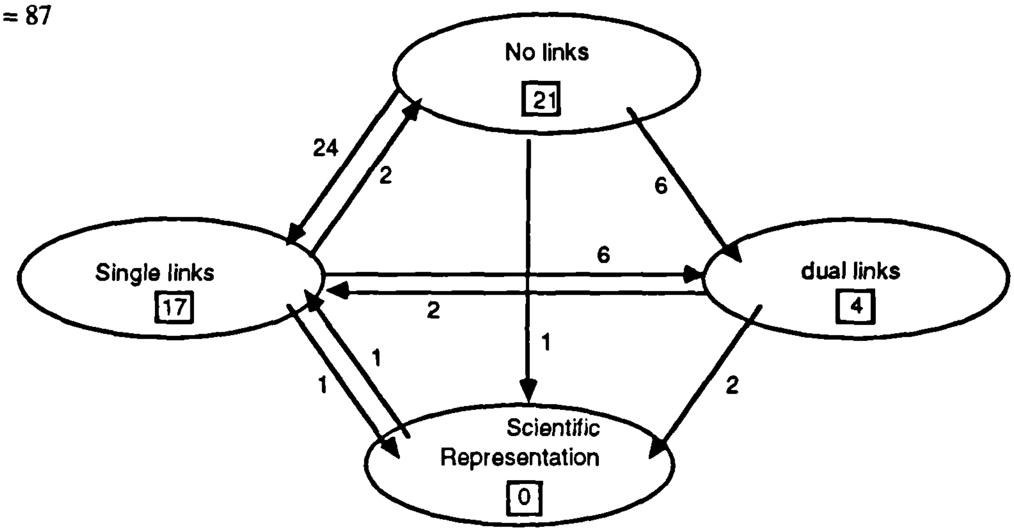
Table 4.12.2.3. Number of children who showed change to a *more sophisticated* representation of light.

The figures show that the predominant shift has been for upper juniors and that the largest shift in the responses provided, is to a representation showing more features of a scientific understanding for primary sources i.e. the candle. This is further evidence that children find it difficult to interpret or explain the phenomena where there is no evident source of light. However, it is worth noting that approximately a third of the upper juniors have improved their representations of what is happening for the book and the candle, both secondary sources of light.

4.12.3. Individual changes in explanations for vision

The data for individual responses which show an explanation for how we see an object are shown in Fig 4.12.3.1 and Fig 4.12.3.2.

No of Items showing
representation of
Vision = 87



Direction of vision
indicated

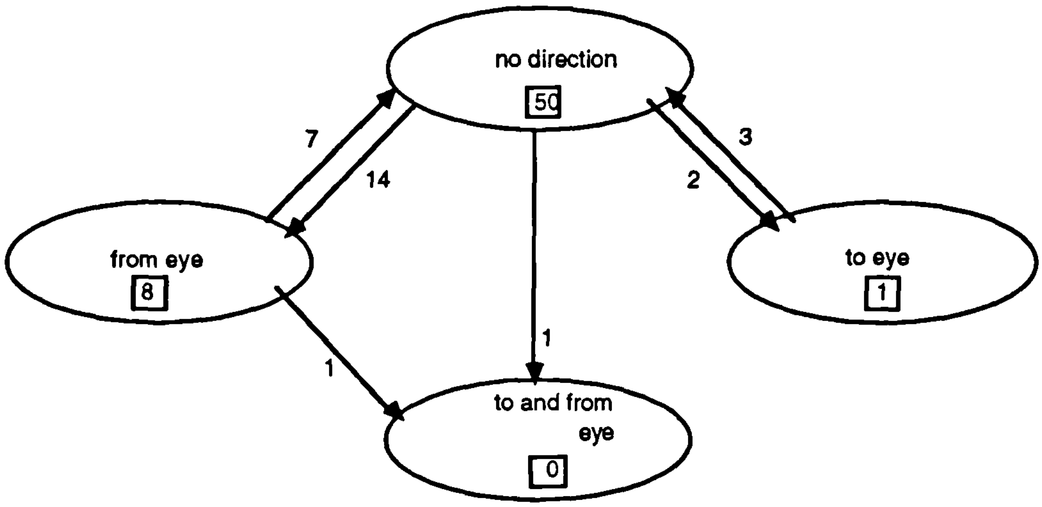


Fig 4.12.3.1. Map of Changes in Children's Understanding of Vision (Lower Juniors)

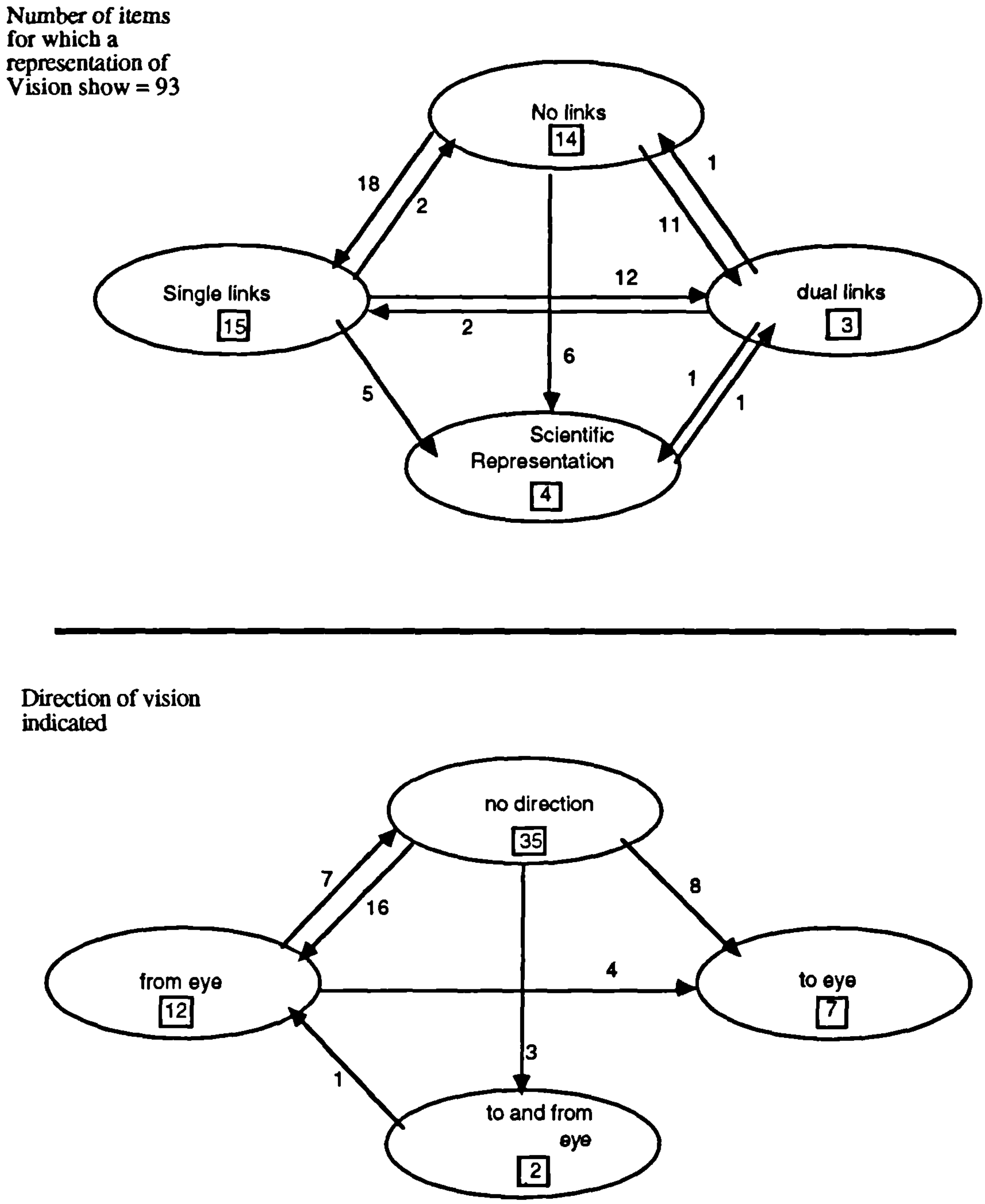


Fig 4.12.3.2. Map of changes in individual children's understanding of vision (Upper Juniors)

Table 4.12.3.1 shows a summary of figures for children's ideas about vision and the changes that occurred. The positive feature that emerges from this table is that there are a large number of changes for both upper and lower juniors to responses that show more features of a scientific model. An analysis of the changes in conjunction with that offered by the network (Fig 4.10.6.1) shows that the main change for lower juniors has been a positive increase in the number of children showing a single link between the eye and the object. Whereas in the case of upper juniors, whilst there has been a positive increase in the number showing a single link, there has also been an *increase in the number using dual links.*

		No Change	*Changes to more features of a scientific Model*	*Changes to fewer features of a scientific model*
UPPER JUNIORS	Vision	36	53	6
(n=95)	Direction	56	31	8
LOWER JUNIORS	Vision	42	40	5
(n=87)	Directions	59	18	10

Table 4.12.3.1. Summary figures for changes in children's ideas of vision.

A similar analysis of individual responses to specific questions about how we see objects was also done and the data are shown in Table 4.12.3.2 and Table 4.12.3.3..

Question	*Candle*	*Book*	*Clock*
UPPER JUNIORS	15(35)	12(31)	9(29)
Direction indicated	17	18	21
LOWER JUNIORS	11(29)	18(29)	13(29)
Direction Indicated	18	21	20

Table 4.12.3.2. Number of children who showed *no change* on questions eliciting ideas about vision.

In comparison to the figures for children's representations of light, the data in Table 4.12.3.2 & table 4.12.3.3. reflects that there has been more change in pupil's models of vision and the ideas that they are using as a result of the intervention. Both these table show a similar improvement for explanations involving a primary source of light, the candle, for both upper and lower juniors. The distinction between the two groups, lies in the improvement for upper juniors in their explanation of how we see a book. Clearly the conceptual demands of understanding how we see a secondary source are not easily accessible to the young child.

Question	*Candle*	*Book*	*Clock*
UPPER JUNIORS	17(35)	18(31)	18(29)
Direction indicated	14	10	7
LOWER JUNIORS	15(29)	9(29)	16(29)
Direction Indicated	7	6	5

Table 4.12.3.3. Number of children who showed change on questions eliciting ideas about vision to a *more sophisticated* understanding.

In all cases the change that has happened has had more effect on the nature of the link than on any sense of direction indicated in the responses. An explanation for this result is difficult to provide, other than that the work helped to establish a more concrete representation of the link between light, source and object, and children may not have considered the direction as being something of substantial significance. Many failed to show any sense of direction in their responses to explain vision or of their representation of light.

In conclusion, these data provide a more detailed picture of where changes in children's ideas have occurred. They support the analysis of the networks, in showing that there has been some change, and that has been most significant for upper juniors. It also shows the lack of stability of children's ideas since the picture presented by the data is one of greater overall change than observed in the network analysis. Not only are children developing, but clearly there are some children whose explanations and ideas are 'regressing'. This would support a model of development for children's ideas which is non-linear which may consist of five steps forward and one step back.

Summary:

a. *An analysis of the changes in individual children shows that a few children provided responses which showed a reduction in the features of a scientific understanding after the intervention. However, the overall effect of the intervention has been to develop the understanding of a large number of children whose responses showed more features of a scientific understanding. However, substantial numbers showed no change in their responses.*

b. *The evidence from these data partially support the analysis provided by the networks, which is that the significant change in understanding has occurred for upper juniors.*

c. *The improvement in explanations of phenomena of explanations associated with secondary sources of light was much more substantial with upper juniors. A third improved their representations of light, and over half their explanations of how we see a book and a clock. Only in the case of their explanations for seeing the clock did the lower junior group make any noticeable improvement.*

5: *Young Children's Understanding of Electricity and its Development*

5.1. Introduction

This chapter is an edited version of the SPACE report (Osborne, Black, Smith, & Meadows, 1991). General issues of methodology and the research programme have already been discussed in section 3, and therefore it begins with an initial review of previous research which provides a context for the work and a framework for the interpretation of the data. Though it should be noted that much of the body of research work in this domain has predominantly been done with children of age 9 or older, and therefore, some of its relevance is questionable. However, the majority of the chapter is devoted to presenting an analysis of the data collected and a discussion of its implications.

5.2. A Review of Previous Research.

5.2.1. Making circuits

Children's understanding of electricity and associated concepts has been an active field of research during the past decade. Most of the work reported has been conducted internationally in New Zealand, the U.K. and America. The work has arisen as part of the general interest in the 'alternative conceptions' movement and has provided valuable insights into the difficulties faced by children in understanding the scientific concepts commonly presented in classrooms.

Early work was done by Andersson and Karrqvist (1979) who presented the diagrams shown in Fig 5.2.1.1 to two groups of thirty four children, age 15 , and asked them whether they thought the lamp would light or not.

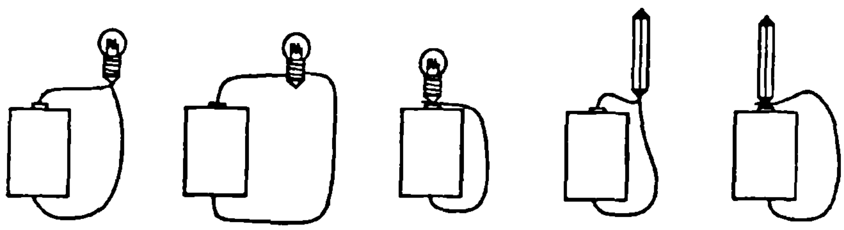


Fig 5.2.1.1. Possible ways of connecting a bulb to a battery

The results were revealing, showing firstly that despite instruction, a large number of children were unable to correctly predict which arrangement would light the bulb.

Moreover, they are an important indicator of the effect of context. Faced with the MES bulb lacking any clue that indicated the presence of two terminals, large numbers of children resort to a model which sees the battery as a 'source' of electricity and the bulb as a 'sink' which need merely be connected to function. Even with the appropriate contextual cue, there was a significant percentage of children who failed to provide the correct response. The result is even more remarkable in that all the children had received instruction deploying MES bulbs in their experimental work.

The work of Tiberghien and Delacôte (1976), Fredette and Lockhead (1980), Osborne (1980) and Shipstone (1984) has lead to the identification of five common models that children hold about electric circuits. These can be summarised as follows.

a. Unipolar.
In this model, the current is supplied from one terminal of the battery only which is all used up by the device to which it is connected by a single wire. Any other wire is not considered necessary or is of no consequence. This model has been identified with an understanding which sees the battery as a source of electricity and the bulb as a sink which consumes the electricity.

b. The series or attenuation model
In this model, the child recognises that an electric circuit needs two wires to function and that the electricity circulates in one direction only. However, more current leaves one terminal than returns at the other as electricity is seen as being 'used up' by bulbs etc. In a circuit with more than one bulb, the first device uses a disproportionate share of the electricity.

Another variation of this model, sometimes termed the 'sharing' model, is where the current is still perceived as being used up by the bulbs/resistors, but each one uses equal amounts of current.

c. The Clashing Currents models
Here the child explains the behaviour of the circuit in terms of two currents which leave via both terminals travelling in opposite directions. The currents meet in the bulb and mix to produce light and heat. Clearly this model has its origins in the notion that positive and negative electricity are two different 'ingredients' of electricity which must be mixed to produce any effect.

d. The Scientific model
This model sees electric charge as a means of transferring energy between one point and another. A complete circuit is required and the rate of flow of charge is the same at all points in the circuit. A full description of this model would examine the role of the

battery in establishing an electric field throughout the conductor and the interaction of the electric charges with the electric field.

Both Shipstone (1984) and Osborne (1980) have conducted large scale surveys of the proportions of each model held by schoolchildren and a summary of results is shown in Fig 5.2.1.2. Both results are similar although the latter's research had a larger sample size which would imply that the results are more reliable.

Not surprisingly, the scientific model which requires making a distinction between energy transfer and its means of transfer - mobile electric charge, is only held by a minority of pupils. Both studies show that the development of the scientific model is barely influenced by relatively extensive periods of instruction in electricity which occur in schools during the secondary phase of education. In addition, both report finding that some of the other models have persisted even with first year undergraduate or post-graduate teachers training to be teachers - effectively more evidence of the strength of these alternative conceptions or the lack of an appropriate pedagogy.

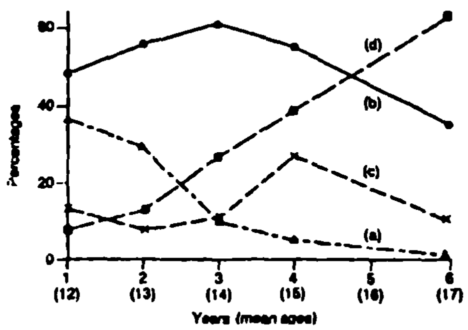


Fig 5.2.1.2. Chart showing range of Models about Electric Circuits held by children from Age 10 - 18 (Shipstone 1984)

5.2.2. Innovative approaches to Teaching Electricity

Cosgrove et al (1984) describe a three phase teaching scheme designed to promote conceptual conflict with respect to their understanding of models of electric circuits for a group of 15 eleven year olds. This consisted of a 'familiarisation' phase, a 'challenge' phase and an 'application' phase. Their data shows that whereas only 7% of children chose the scientific model before the critical lesson, 86% chose it after. One year later, considerable regression had taken place as only 47% chose the scientific model to explain the behaviour of electric currents in circuits. However, the improvement of understanding can still be considered a significant improvement.

Another attempt to address the conceptual difficulties in understanding electric circuits was described by Shipstone and Gunstone (1985). They reported an attempt with a group of 25, twelve to thirteen year olds using an approach that was based on the assumption that most children are operating with the 'source-consumer' model. This idea is more akin to the scientist's notion of electrical energy rather than electrical current. Their programme of activities was designed to challenge this conception and to develop a discrimination between current and energy in a circuit. The results of the research were disappointing in that no significant change was produced in the understanding of the experimental group compared to the control group, although they did outperform the control group in most cases. The proportion of pupils showing long term retention was similar to that reported by Cosgrove et al. (1984). Commenting on the fact that no pupil was successful in more than three questions, Shipstone (1988) argued that this result was indicative of a superficial schema which lacks applicability in a wide range of circumstances and that one of the primary reasons was a lack of any holistic model of the circuit which views the system in its entirety rather than in terms of individual components and their function. Rather, children's thinking about electrical circuits adopted sequential processing which examines the effect of each component in turn.

Haertel (1985, 1987) argued strongly that the failure of many children to understand the behaviour of an electric circuit is due to the use of inappropriate models. The idea of particles transporting energy places an emphasis on the particles themselves, often through the use of vehicular or traffic analogies. A proper treatment of the circuit would consider it as a system where every particle is inter-related to the others. Such an approach would use the bicycle chain, conveyor belts or central heating systems as more appropriate analogies. Although his ideas were tried out in the classroom, no data is provided on the potential for such an approach to develop an improved understanding of electric circuits.

Steinberg (1985) considered that the fundamental problem for children with electric circuits is a phenomenological experience which lacks any sense of causality. The rapid rise in current in a circuit when the switch is closed, fails to provide the opportunity for observing the flow of charge in the circuit. He advocated the use of large capacitors (greater than 1F) which show transient phenomena and force children to consider the flow of charge in the circuit. In an earlier paper (1985), this approach was supported by limited data (n=18) which shows that conceptual change has occurred for the majority of the students.

5.2.3. Epistemological Issues

Monk (1991) has used the data collected by Shayer and Adey (1981) for the distribution of children across developmental stages to suggest that children's' alternative conceptions can best be explained from a genetic epistemological approach.

His basic assumption is that the normative development of children places inherent limits on their potential to explain the problems used by Shipstone (1984) and Osborne (1980) restricting them to concrete models which allow them to centrate on observable features. He then argues none of their data show children exceeding these limits, and that this thesis is a better explanatory framework of the data. Hence whilst schematic knowledge is important, 'common-sense' reasoning used by children limits their understanding of scientific concepts, and the ultimate limit is their ability to cope with abstraction and formal operations. Some further support for this argument is possible from the data presented by Cosgrove et al (1984) which showed a regression in the number of children able to deal with the scientific model from 86% to 47%. Monk argues that the scientific model requires the schematic processing associated with early formal operations which only 30% of children reach by age 16. Whilst this is a convincing argument, it fails to address the issue of how children can develop an appropriate schematic knowledge within such a domain up to their current genetic limits. In particular, it does not consider the principal pedagogic issue raised by the large body of research reported above: that is the application of inappropriate schematic knowledge formulated from everyday experience to problems about electricity.

Rowell and Dawson (1989) argue that novice schemata are based on observables as opposed to expert schemata which are based on explanatory principles and subsume lower level novice schemata. Novice schemata can be used as the basis of inductive generalisations e.g. all electrical devices require two connections to function properly. Such generalisations must conform to reality and can be changed or even refuted by observation. The formulation of a constructive generalisation with explanatory power e.g. conservation of current in a circuit, requires logico-mathematical processing and a teaching process which emphasises the change in the knowledge framework required. Hypothetical entities e.g. electrons, electric charge are inferred and used as a basis for unification and explanation. They argue that the function of preliminary work in science is to prepare a common schema of sufficient complexity for the formulation of constructive generalisations. Their thesis is rare in attempting to synthesise contributions to science education from different schools of thought and the clear implication is that knowledge of a wide range of basic, concrete experiences is an important and essential foundation for the development of scientific knowledge.

An example supporting their argument is provided by Duit (1985) when he suggests that one of the fundamental problems is that the term 'current' is a theoretical generic idea which is inferred from observable effects such as heating or lighting in a circuit. He argues that children then perceive it as an entity which can be stored, moved or used up like other everyday entities. This is a fallacious generalisation which explains some of the ideas provided by children.

Finally, an important illustration of the effect of context was reported by Shipstone (1985). He reported two questions, shown below, examining which of the models (a - e) students deployed to reason about electric circuits. Interestingly, the use of the sequence model was much less common in the second item and this was indicative that contextual cueing was an important aspect of solving problems by children of this age. Shipstone used both of these items in a test and the data he presents show that children clearly see these items as distinctive items which bear no relationship to each other.

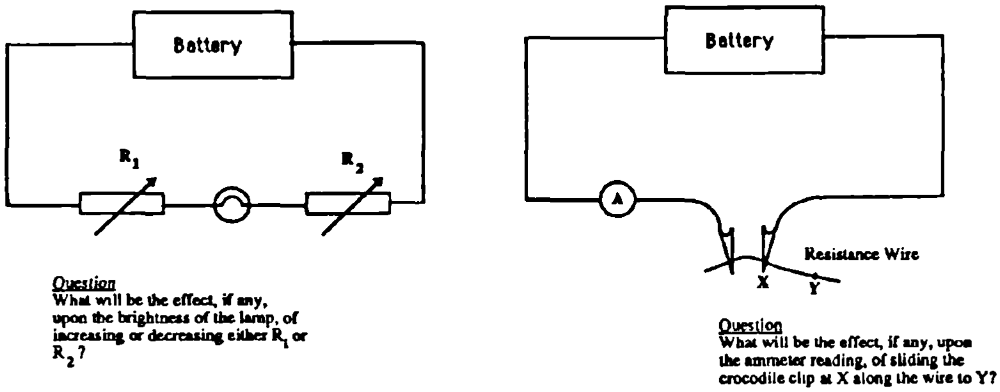


Fig 5.3.3. Items used by Shipstone to investigate models used by children for explaining electric circuits.

In summary, the clear message of this research is that developing an understanding of the phenomenology of an electric circuit is a conceptually difficult task. Therefore the implication for the SPACE research was the need to provide an experiential phase which could allow children a variety of concrete activities from which they may begin to formulate models of the behaviour of electric circuits and electric currents.

5.3. The Research Programme

Classroom work on the topic of 'electricity' took place over a relatively long period in the school year which can be summarised as follows.

Pilot Exploration	March 88
Pre-Intervention Data Collection	April 88
Intervention	May - June 88
Post-Intervention Data Collection	July 88

The pilot exploration phase was based on interviews with a small number of children (25). These interviews used a wide range of questions to explore the nature of children's understanding of the topic of electricity and associated concepts. In addition, drawings and answers to written questions were employed to examine how valuable and reliable such sources were for eliciting children's meanings and understanding. The exploratory nature of this phase was required to supplement what little literature there was available on the nature of young, age 5-11, children's understanding of this topic. Many of the tools devised for probing children's ideas were modifications of methods that had been used with older children. At the end of this phase, the data were examined to formulate a set of questions for the elicitation (Appendix 5a). The intervention activities were informed by the data collected in this phase and a set of learning goals which were felt to be reasonable aspirations for children of this age by the end of their primary schooling were written.

5.3.2 Learning goals for 'Electricity'

Any attempt to develop a child's concepts needs to be based on a map of what a preferred understanding would be. The following list was compiled by the team to provide a map of ideas considered an a priori necessity for the development of the scientist's view.

1. 'Electricity' can move or flow.

2. 'Electricity' is required for a wide range of devices i.e. heating and moving objects, providing light and making magnets.

3. Electrical devices require two connections with wire to a battery to function.

4. The two connections provide a complete path around which 'electricity' can flow.

5. Some materials allow 'electricity' to pass through them and other materials do not. Those which do allow electricity to flow through are called conductors.

6. The strength of 'electricity' is dependent on the number of batteries and the voltage they supply.

7. 'Electricity' can be produced with dynamos.

This list represents a basis or platform for the fuller understanding of the scientist. It suffers from the use of the generic term 'electricity' for electrical energy and electrical charge but such a distinction can not be made with children of the primary age range. The purpose of this list is to provide a framework or point of reference for the research. These statements represent a collection of ideas that children *may* develop by age 11. For example, children need to develop an understanding that two connections are required before they can understand the scientist's picture of current conservation which is generally developed in secondary schools. One of the aims of the research was to examine to what extent, as a consequence of the experiences that were provided by this research programme, such ideas could develop in children and at what ages.

5.3.3. The Pilot Phase

This phase of work was conducted by the research group with 25 children of different ages in clinical interview. The purpose of this was a limited empirical study of the range and nature of responses provided by children to explain phenomena associated with electricity. From these activities a limited subset were selected for use in the elicitation. In this chapter, a fuller description is provided beneath of the activities undertaken to give the reader more detail of the general approach taken during the pilot phase of the work.

a. *Writing three sentences about electricity*

This activity was used as an open-ended activity to explore what associations the word 'electricity' had for children. Children were asked to 'write three things about electricity'. Most children managed to write two or three sentences or features of electricity. Infant children were asked to tell the interviewer three things about electricity.

b. *Objects that use electricity*

The purpose of this activity was to gain some insight into the range of objects that children saw as requiring electricity to function. Children were asked to draw as many objects as they could think of that needed electricity to work, or alternatively write down the names of these objects. It was hoped that this would provide some insight to the range of children's experience of objects associated with electricity and the origin of this experience.

c. *Where does electricity come from?*

This question was used in the interview and responses probed further. The purpose of this question was to explore any ideas children had about the origins of electricity and the models that they were using to express their ideas.

d. *How is electricity made?*

The most common answer to this question was that electricity was made in power stations. However, relatively few children were able to provide this response and a range of answers associating the production of electricity with lightning, transformers and pipes were produced.

f. *What is the difference between electricity from plugs and batteries?*

Responses to this question proved not to be terribly revealing. Children generally held the view that electricity from plugs was stronger than that from batteries, and that it would not last for ever whereas electricity from plugs did. Common responses would be to say that 'batteries run out' and that 'a plug is more powerful than electricity.'

g. *How does a switch work?*

The purpose of this activity was to explore whether children held any model of electricity which could explain the functioning of a switch. This question posed much more of a problem for many children and many were unable to give any answer.

h. *How fast does electricity travel*

Children's responses to this question gave the general impression that electricity travelled very fast using such expressions as 'faster than light' or 'two hundred miles an hour' to convey a general notion of 'very fast'. Few children had any difficulty in responding to this question.

e. *Lighting a bulb*

Children were provided with batteries, wire which had been bared at the ends and a small torch bulb. They were then asked to make the bulb light and record the method that they used. This is not an easy manipulative task so children were asked to work in pairs for this activity. In order to find out whether it was the nature of the connections to the lamp bulb that were problematic for the children, the activity was repeated with a small electric motor where the two terminals were clearly defined. In addition, this activity was also repeated with the components of a Unilab junior electricity kit to examine whether presenting the problem in a different context affected the children's performance on this task. Most children had severe difficulty with this task though it posed less difficulty when using the kit materials.

g. *Materials that conduct electricity*

Children were shown a range of materials e.g. a rubber, a paper clip, a block of wax, covered and bare wire and a plastic comb and asked whether they thought electricity would be able to go through them. The predominant feature of their responses was a lack of any clear idea of which materials would conduct.

h. *What would be the effect of using larger, more batteries.*

This question was asked to explore whether children had any understanding of the notion of voltage. Children were shown a battery lighting a bulb and then asked what would happen if it was replaced by a larger battery.

i. *Static phenomena.*

Several children had mentioned static effects when asked where electricity comes from earlier. Children were shown a comb being rubbed through the interviewer's hair and then being used to pick up small pieces of paper. This activity was used to explore whether children had any deeper knowledge of static electricity and its effects.

Any activities which were found to be non-productive in eliciting children's thinking on the topic were discarded for the elicitation phase. Only one activity was found to be of very little value which was the attempt to explore children's knowledge of static electrical effects with the comb and pieces of paper. Few children had observed this effect and no children were found who could provide any explanation of the phenomenon. Consequently, it was decided to drop this item for the elicitation activities. Full details of the activities used for the elicitation are provided in Appendix 5a and an analysis of the data collected is provided in section 5.5-5.11.

5.4 The Intervention

The data obtained from the elicitation was used informally to provide the teachers with a familiarity and understanding of their children's thinking about electricity. A set of structured activities was then discussed with teachers which would allow children to explore electrical phenomena. All of these activities had a preliminary phase which required the child to hypothesise, predict or speculate about the behaviour of an electrical system using their existing knowledge. Further experiences then provided an opportunity, however limited, for the children to explore their thinking and experimentally test and evaluate their ideas against their observations in collaboration and discussion with their peers and their teacher. These experiences were designed to broaden their schematic knowledge, extend their vocabulary and, where appropriate, generate a conflict between their thinking and experience which would lead to a re-evaluation of their ideas.

The preliminary analysis of the data showed that children held a wide range of ideas about the behaviour of electrical circuits. Many children used simple 'source-sink' models as a hypothesis about how electrical items should be connected to batteries. In addition, there was a lack consistency about their responses. Many children who could show successfully how to connect a bulb to a battery, could not repeat this when presented with an electric motor and battery. As a result of this data, it was considered that the specific knowledge of how to connect an electrical device to a power supply should be addressed by the intervention activities.

Secondly, the preliminary data indicated that many children, especially infants, lacked any clear understanding of which materials would conduct electricity. This uncertainty was apparent when children were shown a range of materials and asked to indicate whether they would conduct or not. A further indication came when children were connecting circuits and some incorporated connecting wires by touching the insulating plastic to the device rather than the bare wire exposed at the ends.

Thirdly, pupils had shown an awareness of a wide variety of objects, particularly domestic objects, which 'use' or 'work' by electricity. However, there was considerable uncertainty about the origin of electricity which came from wire, satellites, lightning as well as power stations.

These findings were then compared with and the framework of scientific ideas defined in 5.3 which the research hoped to assist in developing an understanding of by children. Intervention activities were then designed which were seen as being appropriate to children's existing level of knowledge and understanding and which essentially addressed the following areas.

- The necessity for any circuit to have two connections to a device and an electrical power source.
- Materials can be classified into those which conduct electricity and those which do not.
- Electrical energy can be used for lighting, heating, moving and making magnets.
- Electrical energy can be produced in power stations using dynamos.

It was decided to directly address only these four and not the model of an electric current held by pupils. Children were encouraged to speculate and talk about the electric circuit using terms such as 'flow', 'continuous loops' or 'no break in the circuit' but no attempt was made in the intervention to examine systematically why two connections were needed. One of the basic difficulties faced in this area is that it is impossible to 'see electricity'. All models are inferences based on the effects of electricity and this level of understanding is an aspect which science education seeks to develop in the 11-16 curriculum. The intervention activities (Appendix 5b) were designed to assist in developing the foundations of an appropriate schematic knowledge which further experiences could build on. However, they were not provided to teachers as a prescribed teaching scheme, but rather as a set of activities which teachers could use with children when appropriate to the child's starting point. Teachers were encouraged to always begin by providing an opportunity for the child to use their own ideas as a basis for investigation and prediction. The role of the teacher was to intervene with the suggested material when the child's ideas for exploration and investigation were not fruitful. Thus the role of the teacher was balanced between allowing the child total freedom to explore and providing specific didactic explanation. This is a difficult role which required finesse and experience. However, the starting point for exploration always lay in the children's thinking which was the foundation for the activities briefly described below.

a. Making Connections.

In this activity, pupils were given a light bulb, electric motor, battery and connecting wires. Fahnstock clips were provided to assist the making of connections to wires and the batteries. Children were asked to discuss and draw a picture showing how they would connect the battery to the bulb/motor to make it work. When this was completed they were encouraged to try out their ideas. When, and if they achieved success, they were invited to look at their original drawing and discuss their previous ideas in the light of the result they had just obtained with their peers and their teacher.

The intention of this exercise was that it would challenge the common idea held by many children that only one connection was necessary and force a re-evaluation of their thinking. The idea that two wires are necessary for an electrical device to work is a pre-requisite to developing ideas of current flow and conservation of current. The reason for using more than one device was to provide a wider range of experience so that children did not view the light bulb as a unique object. As well as a motor and a bulb, it had been intended to include a low-voltage electric buzzer for use by the children. However appropriate devices proved difficult to obtain.

Other activities included were making an electromagnet and heating steel wool. In both activities, children were told a minimum amount of information necessary to do the activity. In the case of the former, that an electromagnet could be made by passing electricity through a wire wrapped around a nail. Children were then asked to suggest a strategy for making an electromagnet and testing it.

Heating the steel wool was an opportunity for children to observe the heating effect of electricity through an enjoyable experiment. They were asked to devise a way of making electricity go through the wool and provided with a large battery, wires and connectors. Children were asked to note or draw the method they used which succeeded and to discuss why other methods may not have succeeded. It was hoped that both of these activities would help to develop the idea that two connections to a power source are necessary for any electrical device to function.

In practice, many teachers found that the apparatus often failed to make an effective electromagnet because of the high currents required to achieve an observable effect. Hence many children did not attempt this activity.

The activities in a second set were of a simpler observational nature. These involved examining bulbs and mains wires. Children were asked to draw what they would expect to see if they looked inside. They were then provided with specimens of each and allowed to cut open the wire and given a magnifying glass to look at the bulb and asked to sketch what they could see. It was hoped that the opportunity to see that a mains cable is not a single wire and that light bulbs have two wires going to the filament would help to support a model which saw devices requiring two connections to function.

A similar activity was devised with batteries. Children were provided with two batteries, a bulb and connectors and asked to show how they would make a circuit with two batteries in it. The opportunity was then provided to test such a circuit and observe its effect. Children were also provided with a range of batteries and asked to draw them and note features common to all. Those supplied varied in size and voltage. They were then asked to predict which would light the lamp most brightly and place them in an order. An opportunity was then provided to test the effect of using the different batteries with 4.5 V bulb which does not blow. This experiment was designed to challenge intuitive notions that the largest batteries are the strongest and to develop a tacit understanding that the brightness of the lamps followed the pattern of numbers with a capital letter 'V' after them.

b. Materials which conduct electricity

An open-ended activity was designed for use with children. Children were given a bulb and holder, connectors and a battery and asked to work as a group and devise a way of testing objects to find out which ones let electricity pass through. Children were encouraged to test their ideas of how the bulb should be connected to function. Teachers were asked to assist pupils who had difficulty thinking of an appropriate mechanism for tackling the problem. Children were then asked to collect a range of common materials from their classroom and construct a table with their prediction for each material of whether it would let electricity pass and find the answer by testing it. The approaches to this activity reflected the range of styles that were used by teachers. Some allowed the children to work collaboratively in groups whilst some teachers preferred to work with the class as a whole, allowing them to predict and perform the experiment and acting as a central recorder of results. The activity itself provided rapid feedback as to the validity of their guesses.

An extension of this activity was to ask pupils to make a switch. Many pupils simply suggested breaking the circuit in some way and others made switches successfully from drawing pins and paper clips. The function of this activity was to develop a simple picture of a switch and reinforce the concept of a circuit which had been tackled previously. Children had to construct complete, working circuits before they could make switches. Unfortunately, there was insufficient time to explore whether children saw the position of the switch in the circuit as being important.

c. *Where does electricity come from?*

This section of the intervention aimed to develop children's ideas about sources of electrical power or energy. Opportunities for practical work in this area are limited by the resources available to schools though hand operated dynamos were supplied so that children could have an opportunity to explore generating electricity for themselves. It was decided that the main focus of the work here should be through collaborative work based on the use of secondary sources. Children were asked to discuss and write their ideas about the objects and places it was possible to get electricity from. A selection of books was provided and children told that they had to produce a poster with the heading 'Where electricity comes from.' The work was reliant on secondary sources but involved the children, through discussion, in the active construction of a report.

5.5 Children's Ideas about Electricity and their development: Introduction

This section provides a full analysis of the data gathered during this study. Data presented here shows children's responses to questions about:

a. Uses of Electricity
b. Ideas about electricity
c. Circuits and their connections
d. Materials that conduct electricity and how to test for conduction
e. The effect of more batteries on a circuit.

These data analysed here are those gathered in two phases, the elicitation phase prior to the intervention and a second elicitation phase after the intervention. In both phases, the elicitation work consisted of a large collection of activities which were designed to stimulate children to talk, write and draw their ideas about electricity and phenomena associated with electricity (Appendix 5a).

In order to improve the reliability of the data, redundancy was built into some of the elicitation activities through the use of duplicated items that differed in their context so that the consistency of the responses provided by each individual child could be evaluated.

The data presented are those obtained from children who were present on all both occasions i.e. for the first elicitation and the final elicitation. Full sets of data were collected from 107 children in total (n = 62 for upper juniors, n = 27 for infants, n= 18 for lower juniors). Sample sizes for the different age groups varied considerably depending upon the availability of classes and children as difficulties were experienced in some schools due to staff mobility, timetable pressures and absences of children.

However, the data sample has been considered large enough to present a frequency analysis of many of the responses. Much of this was done using systemic networks (Bliss, Ogborn & Monk, 1983).

5.6 Uses of Electricity

The elicitation activities had two specific items which produced responses about the uses or function of electricity. All children were asked 'What do we use electricity for?' and children older than 7 were asked to write three sentences with the word 'electricity' in. Infant children were asked this question in individual interviews. The former question tended to produce lists from children of typical items. The latter question was more open ended and responses such as 'electricity works lights' were considered a recognition by the child of a specified use.

In all, children mentioned 54 appliances that used electricity. These were cookers, lights, heaters or fires, television, irons, kettles, video recorders, fridges, radios, freezers, tape recorders, telephones, washing machines, hoovers, keyboards, hi-fi and stereos, toys, hairdryer, tumbledryer, microwaves, grills ,toasters, torches, computers, shavers, lawnmower, camera, batteries, motorboats, cars, machines, food processors, doorbells, plugs, switches, piano, buses, drill, aeroplanes, clocks, cement mixers, helicopter, machines, sewing machines, spinners, meters, buildings, tube (underground), typewriters, houses, motors, lightning, motor bikes, taxis, lorries, and appliances.

	Pre			Post		
Items	*Infants* %	*Lower Juniors* %	*Upper Juniors* %	*Infants* %	*Lower Juniors* %	*Upper Juniors* %
Cooker	22	50	39	48	50	56
Lights	56	61	82	56	41	66
Heaters/Fires	22	0	19	19	33	21
T.V.	41	50	60	22	33	39
Irons	4	6	6	15	11	18
Kettles	0	0	5	4	0	10
Videos	0	0	6	7	6	15
Fridges	0	0	13	0	0	11
Radios	4	6	23	4	6	21
Telephones	0	11	13	4	22	11
Washing Machine	7	0	8	0	0	13
Microwave	0	17	11	0	0	5
Computers	4	11	10	0	0	3

Table 5.6.1. Percentage of children indicating items which used electricity.

The obvious feature of this list of items is that it reflects a preponderance of domestic items which shows that the main context for the development of a child's knowledge of electricity is the home. Only a few of these uses were mentioned by more than 10% of any age group and Table 5.6.1 shows which items these were.

It is clear from these figures that most children are able to specify a range of domestic items which require electricity to function. These responses were tested for significance to see whether there had been any change in the distribution or number as a consequence of the intervention. None were found to have any significance and this implies that children's ideas of the range of uses of electricity were not affected by the intervention. The intervention did not seek to extend children's knowledge of the range of uses of electrical energy so this result is not surprising.

Because of the imbalance of the samples, with the preponderance of data obtained from upper juniors, it is not meaningful to group the data into one total for the responses prior to the intervention and another for those post-intervention as such a method would be too weighted to the upper junior sample. Such a procedure if possible, has value in providing a view of the overall effect of the intervention.

5.7 Ideas About Electricity

The elicitation activities included a range of questions which asked children about the nature of electricity and its properties. Particular questions which elicited data were

'Write three sentences about electricity.'

'What is electricity like?'

'Where does electricity come from?'

'How fast does electricity go?'

'What do we use electricity for?'

The predominant feature of children's writing about electricity was an association of electricity with function, as the following responses to question 2 or 5 (Appendix 5a) show.

'You will find if you have an electric cooker that it uses electricity. I have electricity in all of my lights'.	Anne: Age 10
'Electricity helps us in the home.'	Jane: Age 11.
Electricity is a very strong form of power, it runs all sorts of things.....it would be hard to live without it.'	Harry: Age 10

The picture that emerges from these statements is that electricity is seen as a pervasive and universal 'substance' which is required to work or power most machinery. In a stronger form, electricity is viewed as an essential prerequisite for life which is reflected in the following statements.

'Electricity is part of our lives'	Jane: Age 9
'Electricity is very useful. Electricity is used every day.'	Joseph: Age 10.
'We could not live without electricity'	Daniel: Age 10.

Such statements were more common with older children which gives some indication that these children are prepared to recognise a concept of electricity which is not associated with the functioning of specific machinery, and that they were beginning to recognise electricity as an independent entity.

The danger of electricity is a clear feature which was evident from children's responses, though in all cases it was only mentioned by a minority of children. The following are representative statements of the responses provided by children. This feature of children's knowledge of electricity has been documented before by Solomon, Black et al (1985)

'Electricity is dangerous you can kill yourself.'	Matilda: Age 6.
'Electricity can give you a shock.'	Natasha: Age 9.

'You could get an electric shock from electricity.' Makeda: Age 10

A minority of pupils made statements linking electricity to gas such as 'electricity is like gas' of which the following are examples.

'Electricity is hot.....fire...comes from big gas things.' Steven: Age 7.

'Electricity comes from gas.' Wayne: Age 10

'Electricity is like gas..you can't see it, it is dangerous and it helps things work.' Wayne: Age 8

The association with 'gas' may also be an attempt by children to provide a more substantive concrete analogy for electricity.

However, the predominant impression that emerges from an examination of the statements about the 'qualities' of electricity is the impression that electricity was seen by children as a vitalistic element, that is it is necessary for life, or an ingredient of machines, both of which are essential for human comfort and warmth. The latter association may account for comparison with gas which is also used for providing warmth and indicates that the children were intuitively recognising that both were sources of energy. Several statements were collected associating electricity with burning which also helps to develop the idea that electricity is 'hot'.

'One day I was putting my light on and.....I turned to turn my light off and it burns my house. It burns...my tele was burnt.' Layi: Age 7

'Burn you....when I was a little baby, I went to hospital.' Danny: Age 5

'If you put a plug .....in the socket and you put it in there a million times, then it might blow and raise a fire.' Alex: Age 6.

More statements associating electricity with fire and warmth were obtained from infant children and reflect an awareness of the danger of electricity which has probably been instilled by their parents. Interestingly, older children tended to give answers that identified some of the properties of electricity e.g.

'You cannot see electricity.' Mark: Age 9

'Electricity is like magic.' Acima: Age 10

Children provided a range of statements and Table 5.7.1 shows the median number of aspects or 'qualities' of electricity described by children.

	Infants		*Lower Juniors*		*Upper Juniors*	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Median No of statements	3	3	2	2	2	3

Table 5.7.1: Median Number of statements about aspects of electricity by pupils

Thus the answers to these questions provided a large body of data reflecting of children's understanding of electricity. These data were summarised using network analysis, Fig 5.7.1 (Bliss, Ogborn & Monk, 1983) which gives an overview of the range and nature of their responses.

A statistical analysis of the network shows that there are only three significant changes for statements about the 'qualities' of electricity after the intervention. The number of infants who made descriptive statements about electricity rises from 9 to 19 of the pupils ($p<.01$); the number of lower juniors who made statements associating electricity with warmth and energy rises from 1 child to 7 ($p<0.05$); and the number of upper juniors who made statements saying that electricity is 'needed for living' rose from 6 to 20 ($p<0.01$). Given that there is no pattern to these changes and that in most instances, there was no change in children's statements, this does suggest that intervention had little effect on changing children's perceptions or models of electricity. This result was not surprising since the data suggests that children's models of electricity were concrete in that the predominant aspects of electricity mentioned are everyday observable features e.g. that it is used to make machines work; is dangerous and can be used for heating. These aspects would have predominantly been reinforced by the intervention activities.

Question 14 which was designed to explore whether children were aware of any difference between electricity from the mains and electricity from batteries, generally failed to elicit any significant response from infant children other than 'Don't know'. There was some doubt as to whether infant children even perceive batteries as being associated with electricity.

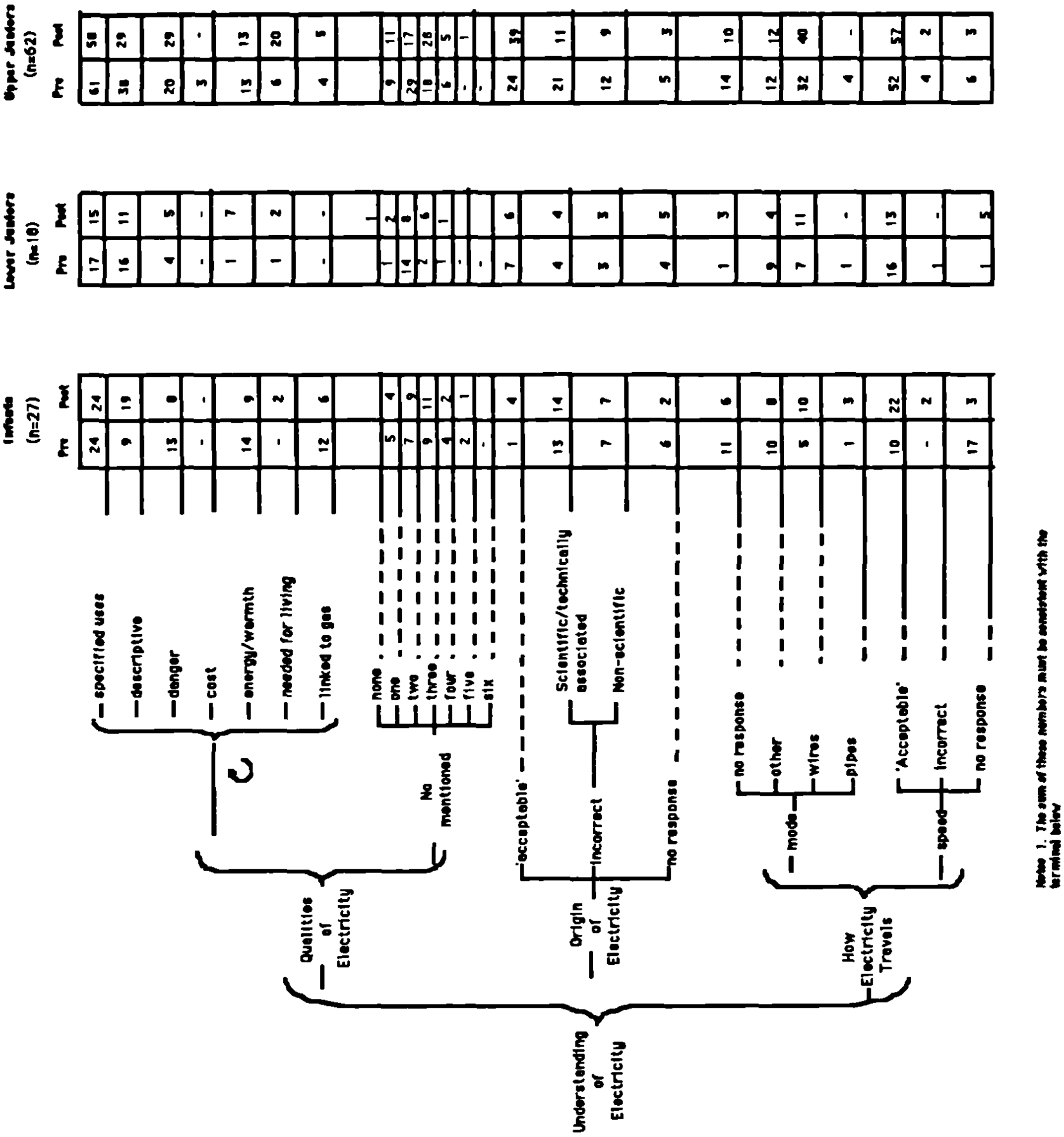


Fig 5.7.1: Network showing summary of children's thinking about aspects of electricity

Children were also asked 'Where does electricity come from?' (Q1) and 'How does it get here?' (Q13) and these two questions produced a wide variety of responses. Some children responded that it came from 'power stations' or 'electricity stations'. However a considerable number associated the origin of electricity with the sun or lightning or even in the occasional case, satellites.

> *'Electricity is like lightning that comes from space - it hits the wires that are on the street and it goes to the top of your house and makes the telephone work. All the electricity goes down to the control box in your house.'*
>
> Farrukh: Age 8.
>
> *'Electricity is in the sun.'*
>
> Westley: Age 10.

'I think electricity gets here by satellite.' Kelly Ann: Age 9.

Many children said that electricity got here by wires, cables or pipes or 'from underground' which presumably led to the association by a few children of electricity with water which were both seen as coming 'through pipes'.

Other responses show how younger children are attempting to make sense of the varied sources of information and observations to which they are exposed e.g.

Sonia: Age 8	*'Electricity comes from God.'*
Interviewer:	*'How does it get here?'*
Sonia: '	*God brings it and puts it in those big round things (points to nearby gasometers).*
Interviewer:	*'How does he do that without us seeing?'*
Sonia: '	*He made the round things before he made people and he put electricity in them.'*

Interviewer.	*'Where does electricity come from?'*
Alex: Age 6.	*'You buy it.'*
Interviewer:	*'Where from?'*
Alex:	*'Shops'*
Interviewer:	*'How do you get it home?'*
Alex:	*'You take it home.'*

Interviewer:	*'Where does electricity come from?'*
Shantelle: Age 6.	*'It comes from a kind of house.'*
Interviewer:	*'What kind of house?'*
Shantelle:	*'All electricity in it.'*

Such responses show clearly that for some children certain artefacts were associated with electricity but there was a lack of differentiation between one object and another in its purpose and function. This suggests that the schematic knowledge of the children is isolated and fragmented and lacks any model which enable distinctions to be made.

Statements about the origin of electricity were categorised into 'acceptable' which was a broad category which included statements such as 'from the electricity house.'. A second category, 'incorrect', in which there were two categories of response, those that were technically associated e.g. 'it comes from gas' and those that were clearly non-scientific e.g. 'it comes from the sun' or 'it comes from lightning'. The final category was those children who were unable to give a response or gave an unintelligible response. The network shows that the majority of children are able to provide some response which, if not correct, has scientific associations and that the number of children providing such responses increases with age. However a statistical analysis of the network shows that a significant shift ($p<0.05$) has only occurred for upper juniors where the number of children providing an acceptable response has increased from 24 out of 62 to 39 out of 62. Whilst this is promising and indicative of a positive development, it shows that an understanding of where electricity comes from has not been developed for younger children. Given the previous evidence that children's thinking about the use of electricity is predominantly based in a domestic environment, and that approaches to developing any understanding of the origin of electricity are inevitably based on secondary sources, children's experience at this age has given them little opportunity to develop any understanding of the generation and production of electricity.

The final major feature of children's responses was their ideas about how electricity travels. The idea that electricity travels on wires clearly emerges as the predominant idea by the age of eleven. There were a few children who thought that it travelled in pipes either because they were confusing it with gas or more likely, given the urban environment in which the research was conducted, that they were correctly stating how they see electricity arriving.

The other question children were asked was 'How fast does electricity go?' (Q9) and the predominant response to this question indicated that most children had the impression that electricity travelled very fast. Typical answers state that it went 'very, very fast' or attempted to quantify its speed in terms of a number that was considered very fast e.g. '200 miles per hour', '30,000 miles a second.'. The occasional response indicated the reasoning underpinning this belief.

> *'It must go very fast....faster than Concorde because you can phone to France in about 10 seconds, so electricity can get to France that quickly.'*
>
> Robert: Age 10.

It was hoped that the range of questions used would provide more information about children's models of electricity but the items used failed to reveal their models in greater depth. Question 10 about switches and how they functioned generally elicited disappointing answers which described switches working when pressed or 'by electricity'. Partly this was due to the question which failed to place any emphasis on the internal working of the switch, but it also revealed that very few children had any idea of what was inside a switch and how it operated. Some responses used metaphors that were consistent with a 'water model'.

> *'When you turn on the switch, you let electricity through the pipe.'* Daniel: Age 9

Statistical analysis shows that there was no significant change in the distribution of children's answers about the mode of travel as a consequence of the intervention. There was a significant change ($p<0.01$) in infants ideas about the speed at which electricity travelled. The number who provided an 'acceptable' answer increased from 10 out of 27 to 22 out of 27. The intervention did not directly address this idea but this result would indicate that it is one of the more perceptible features of the behaviour of electric circuits which infant children notice.

Overall, there are very few significant changes in children's ideas about the 'qualities' and behaviour of electricity as a consequence of the intervention. Since electricity is effectively imperceptible, all the concrete experiences of its behaviour and properties are of its effects and any understanding has to be inferred from these. The notion that it travels fast is easy to deduce from simple experiments with switches but an understanding of its origin, its mode of travel and use as a means of transferring energy are abstractions for many children which lack substantive evidence from their everyday lives. In summary, the table 5.7.2. shows the predominant properties mentioned by children and the percentages that made mention of them.

Property	*Infants* Pre %	Post %	*Lower Juniors* Pre %	Post %	*Upper Juniors* Pre %	Post %
Specified Use of electricity	88	88	94	83	98	94
Descriptive statement	33	70	88	61	61	47
Danger of electricity	48	30	22	28	32	47
Electricity is needed for energy or warmth	52	33	6	39	21	21

Table 5.7.2: % of children who mention particular properties of electricity.

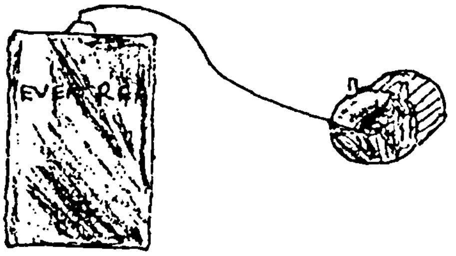
5.8. Circuits and their connections

Much early education about electricity seeks to establish an understanding that a complete circuit is necessary for an electrical device to function. Consequently, the models held by children about the appropriate connections necessary to light a bulb or drive an electric motor were of particular interest. In the elicitation activities, three drawings were presented to children and the children asked to add to the drawing to show how they would get the bulb/motor to light.

Children's answers fell into the following categories.

a. A single connection.

Many children provided a drawing indicating a single connection between the battery and the bulb to show how to light the bulb. This source to sink model was produced extensively and reflects an understanding which sees the battery as a source of power, the light/ motor as the consumer and the wire as the necessary link to enable the supply. Some children drew this response even when they were aware that it failed in practice to light the bulb. Typical examples are shown in Fig 5.8.1a and Fig 5.8.1b



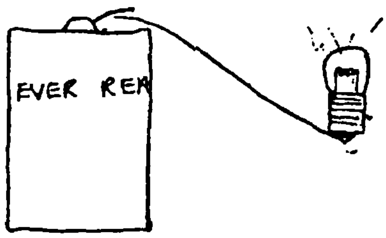
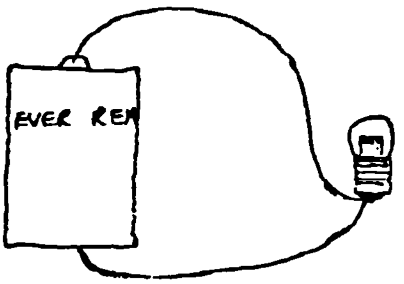


Fig 5.8.1a: Tom - Age 7 **Fig 5.8.1b: Dano - Age 9:**
Responses showing single connection between battery and bulb

b. Two battery connections, 1 device connection.

These children showed an awareness of the need for two wires coming from the battery but were not aware of the need to join the wires to separate points on the bulb or the motor. Typical examples are shown in Fig 5.8.2a and Fig 5.8.2b



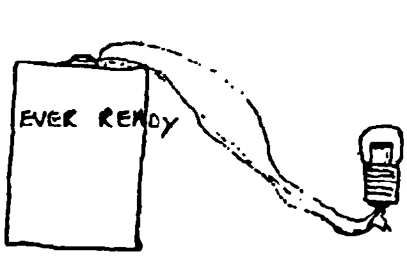


Fig 5.8.2b: Julie Age 6. **Fig 5.8.2b: Makeda - Age 10**
Connection to battery with two connections (incorrect)

Such responses were considered indicative of a more sophisticated idea about the physical requirements necessary for a circuit. Previous research has argued that such a model is consistent with the idea that electricity consists of two ingredients, positive and negative, and that children see the mixing of these two ingredients as necessary for anything to work. Such drawings would be consistent with such an idea or, more simply, they may show a failure to recognise the two connecting points on a MES bulb.

c. *2 Battery connections, 2 device connections.*

A third type of response showed two battery connections and two device connections but in the wrong places. Such responses were relatively rare and were presumed to indicate an awareness of the need to have two wires attached to different points on the device. However, there was a lack of knowledge about which points on the device the wires should be connected to.

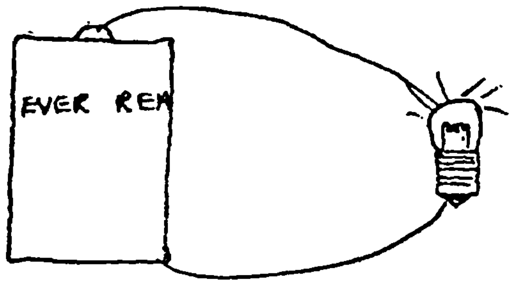


Fig 5.8.3: Hayley - Age 11. Example of two battery and two device connections (incorrect)

In the case of the motor, there was a large number of responses of the type shown in Fig 5.8.4. These responses were taken to be an attempt by the child to show the correct method of completing the circuit.

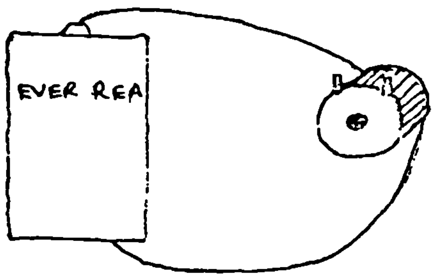


Fig 5.8.4: Child - Age 11: Drawing showing battery connected to a motor (incomplete)

d. Two correct connections shown

Many children were able to indicate correctly the connections necessary to make the lamp or bulb function, particularly during the post elicitation. Fig 5.8.5 shows a typical drawing produced by children.

Fig 5.8.5: David - Age 5. Drawing showing correct connections between a battery and a bulb.

One or two children indicated that they saw the operation of the circuit in terms of a flow by adding arrows to the diagrams (Fig 5.8.6).

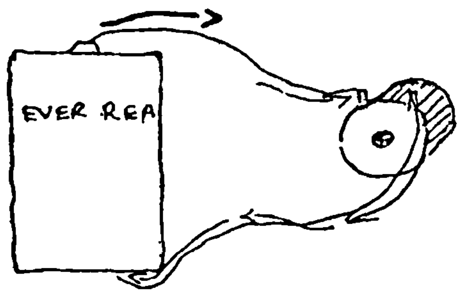


Fig 5.8.6: Harry - Age 10. Drawing showing directions of current flow in a circuit

What was notable was the change over the intervention from the predominance of unipolar models of electric circuits to models which showed a recognition of the need for a complete circuit and two wires.

However, such responses were rare and unfortunately there was insufficient time to explore what models children had of the behaviour of the electricity in the circuit and this is a key area that needs to be addressed by future research.

e. No response

There were a number of children who simply failed to draw an answer to the question (Q3). No attempt was made to explore why they were unable to provide any answer but the number doing so reduced after the intervention.

The results obtained were analysed with the use of another network to provide a summary of children's understanding of the connections necessary to make electrical devices work (Fig 5.8.7). The network shows the number of links and their associated arrangements together with the consistency of the response provided by children. It was hoped that this would provide some insight into the model being used by the child for their responses.

The network shows that large numbers of children prior to any intervention use single connections between the battery and motor/lamp which reflects that the model being used by children is a simple source-sink model. This is shown more effectively in Table 5.8.1, 5.8.2, 5.8.3. The figures shown here are the percentage of the total responses of any one type, that is 33% of the infants responses prior to the intervention showed a single connection.

Infants

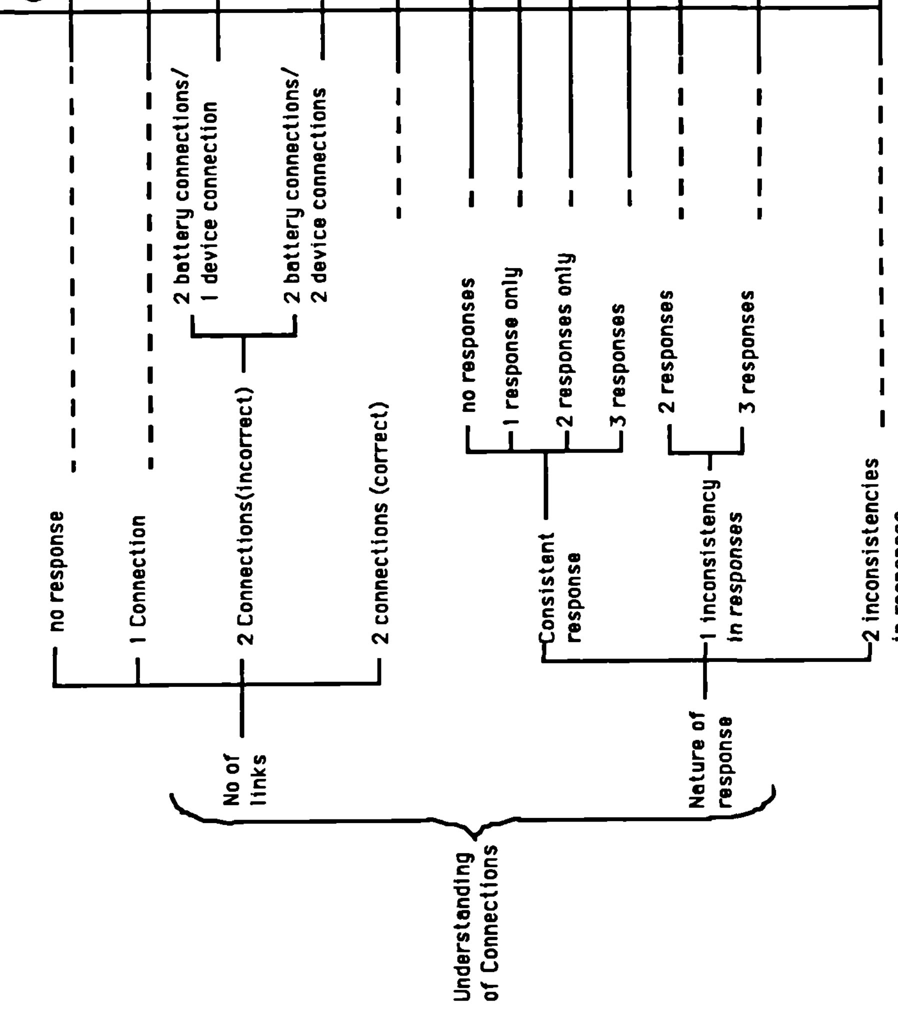
	Pre %	*Post* %
No response	46	20
1 Connection	33	33
2 battery, 1 device connection	9	9
2 battery, 2 device connections	4	20
2 Connections (Correctly indicated)	9	19

Table 5.8.1: Nature of responses provided by infants showing how to connect an electrical device (%)

Lower Juniors

	Pre %	*Post* %
No response	17	13
1 Connection	24	13
2 battery, 1 device connection	7	13
2 battery, 2 device connections	11	7
2 Connections (Correctly indicated)	41	54

Table 5.8.2: Nature of responses provided by lower juniors showing how to connect an electrical device (%)



Category	Infants (n=27) Pre	Infants (n=27) Post	Lower Juniors (n=18) Pre	Lower Juniors (n=18) Post	Upper Juniors (n=62) Pre	Upper Juniors (n=62) Post
no response	(37)	(16)	(9)	(7)	(30)	(11)
1 Connection	27	27	13	7	70	23
2 battery connections/ 1 device connection	7	7	4	7	22	28
2 battery connections/ 2 device connections	3	16	6	4	4	10
2 connections (correct)	7	15	22	29	60	114
no responses	9	-	-	-	-	-
1 response only	1	1	2	-	5	-
2 responses only	6	5	3	5	14	3
3 responses	1	-	-	1	21	19
2 responses	2	9	2	2	6	8
3 responses	6	7	10	5	12	27
2 inconsistencies in responses	2	5	1	5	4	5

Fig 5.8.7. Network showing children's ideas about how to connect a circuit for an electrical device.

With the exception of infant children prior to the intervention, tables 5.8.1 - 5.8.3 show that nearly all children used a more complex model with two connections to show how the device should be connected though only a minority were able to show how to attach the wires correctly. The implication of the latter result is that it may not be helpful to start teaching electricity with bulbs where the two connecting points are not obvious. Children should be provided with an initial opportunity to investigate electrical devices to establish how many connecting points they do have.

Upper Juniors

	Pre %	*Post* %
No response	16	7
1 Connection	37	12
2 battery, 1 device connection	12	15
2 battery, 2 device connections	2	5
2 Connections (Correctly indicated)	32	61

Table 5.8.3: Nature of responses provided by upper juniors showing how to connect an electrical device (%)

Statistical analysis reveals that the changes in the responses of how to connect a circuit were highly significant improvements for infants ($p<0.001$) and upper juniors ($p<0.001$) but the changes for lower juniors were not significant. This behaviour is somewhat anomalous but may be due to the small sample size used for lower juniors. Overall the results show that for all children, the changes were highly significant ($p<0.001$) though the sample was heavily weighted to upper junior children who showed a significant change in their responses. However this data shows that the provision of practical experiences with electrical circuits is a valuable component in developing operational knowledge.

Another notable aspect of children's responses was the lack of consistency about their responses. A sizeable minority of infants and upper juniors and a majority of lower juniors, who could show successfully how to connect a motor to a battery, could not repeat this when presented with a bulb and battery or vice versa. Fig 5.8.8 shows such a response.

This result is interesting in that it shows clear evidence that even within a confined domain, children's responses are dependent on context. Such behaviour has already been noted in the work undertaken previously on light(see section 4.10). These instances show that the child perceived them as being distinct, centrating on the observable concrete distinctions and lacked any model which would allow them to recognise the similarity.

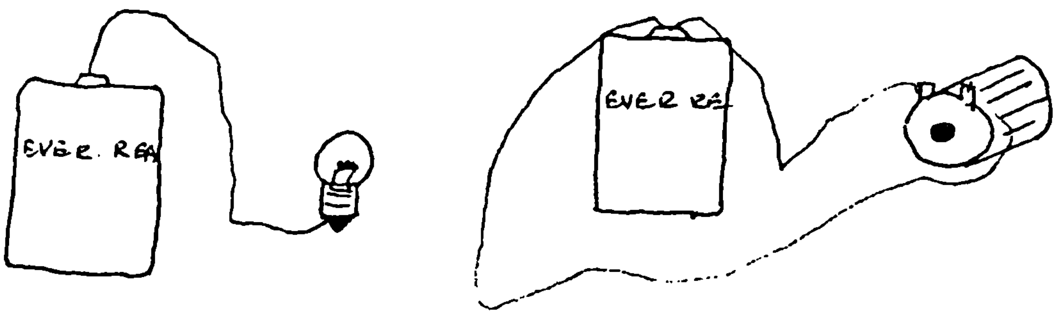


Fig 5.8.8: An example of inconsistent responses to similar questions asking how the bulb/motor should be connected to work

Therefore, the other half of the network was an attempt to examine how consistent children's responses were. This would provide some insight into the strength of the ideas they were using and the effect of context. The results are summarised in Table 5.8.4.

	Infants		*Lower Juniors*		*Upper Juniors*	
	Pre %	Post %	Pre %	Post %	Pre %	Post %
Consistent	63	22	28	33	65	35
One Inconsistency	30	59	66	39	29	56
No Consistent Response	7	19	6	28	6	8

Table 5.8.4: Percentage of responses from children and their nature.

These results show that for infants and upper juniors the effect of the intervention has been to decrease the consistency of the responses provided. The data for lower juniors were inconclusive. A very small contribution to the count for consistent responses before the intervention was those children who provided only one response[1]. Such individuals cannot truly be said to have provided a consistent response. However their contribution would not change the overall pattern of results and it suggests that the effect of the intervention is to increase the range of responses and the context dependence of their answers. An examination of the data for the connections suggests that there was a decline in responses which showed single connections which was

1 See terminal "1 response only" in Fig 5.8.7.

accompanied by an increase in those which showed two correct connections, even if they were not totally consistently applied. This effect was most marked with upper junior children.

One possible explanation of such results is that experiences provided for children by the intervention challenged their intuitive notions in specific contexts. Many children, realising the inadequacy of their thinking for *a specific example*, changed their response in this context to one which was more complex. This could be seen as a phase of confusion and was indicative that the child lacked sufficient capability to generalise from a limited range of experiences. In effect, the waters have been muddied but not changed, and only those children who have developed an altered generalisable theory will show an improvement in their understanding with the use of a consistent response.

5.9 Materials that conduct electricity and how to test for conduction

One activity in the elicitation looked at the understanding children held of materials that conduct electricity. Children were shown a variety of materials and asked if they would let electricity pass through them. The main purpose of this activity was to see whether children were aware that there were a group of materials called 'metals' which conducted electricity.

The six materials used were three non-conductors, a wax candle, a cork and a plastic comb and three conductors, a paper clip, a piece of kitchen foil and some household scissors. Table 5.9.1 shows the responses obtained from upper juniors, table 5.9.2 from lower juniors and table 5.9.3 from infants for the materials used. Each table shows the number of responses obtained before and after the intervention in the three categories of 'yes-it will conduct/let electricity pass', 'no it will not conduct/let electricity pass' and 'don't know'.

	YES		NO		DON'T KNOW	
	Pre %	Post %	Pre %	Post %	Pre %	Post %
Wax	16	11	69	81	15	8
Cork	19	18	66	74	15	8
Comb	27	19	61	65	11	16
Scissors	63	85	23	6	15	8*
Foil	74	77	16	5	10	18
Paper Clip	76	90	11	5	13	5

Table 5.9.1. Table showing percentage of Upper Juniors giving each response to question asking whether materials conducted. (n=62)

	YES		NO		DON'T KNOW	
	Pre %	Post %	Pre %	Post %	Pre %	Post %
Wax	6	17	50	83	44	0**
Cork	11	17	72	72	17	11
Comb	17	0	56	89	28	11
Scissors	44	72	17	6	39	22
Foil	61	44	17	33	22	22
Paper Clip	56	72	22	22	22	6

Table 5.9.2. Table showing percentage of Lower Juniors giving each response to question asking whether materials conducted. (n=18)

	YES		NO		DON'T KNOW	
	Pre %	Post %	Pre %	Post %	Pre %	Post %
Wax	26	11	52	85	22	4*
Cork	37	26	37	67	26	7
Comb	22	26	59	74	19	0
Scissors	30	67	63	26	7	7*
Foil	41	85	41	7	18	7*
Paper Clip	48	67	41	26	11	7

Table 5.9.3. Table showing percentage of Infants giving each response to question asking whether materials conducted. (n=27)

** Changes which are significant at the level of $p<0.01$

* Changes which are significant at the level of $p<.05$

Another way of looking at these tables is to aggregate the data for those that are conductors and those that are insulators and see what percentage of each grouping did get the correct answer.

Property	***YES will conduct***		***NO will not conduct***		***DON'T KNOW***	
	Pre %	Post %	Pre %	Post %	Pre %	Post %
Conductors						
Infants	40	73	48	20	7	7
Lower Juniors	54	63	19	20	28	15
Upper Juniors	71	84	18	5	13`	10
Insulators						
Infants	28	22	51	76	22	4
Lower Juniors	11	11	59	81	30	6
Upper Juniors	21	16	65	73	14	11

Table 5.9.4: Percentage of each type of response given by infants, lower juniors and upper juniors about the ability of materials to conduct

The data show quite clearly that upper junior children had a fairly clear idea of which materials will conduct electricity and that those ideas were essentially correct with a large number of children making the correct predictions about whether materials will or will not pass electricity.

The data for lower juniors show a similar pattern, though with a smaller sample the evidence is not quite as distinct. However, even from this sample, it is possible to conclude that the majority of lower junior children were capable of distinguishing non-conductors of electricity from conductors.

The data for infants showed little evidence that children prior to the intervention had any clear idea of which materials would conduct electricity with more children saying that scissors would not conduct than those saying it would. However, it is notable that the intervention has had the effect of changing children's perceptions so that the majority of children were capable of correctly identifying those materials which will conduct electricity afterwards and this change approaches significance at the .05 level. These results would indicate that an understanding of which materials conduct electricity was evolving across the age range possibly as a consequence of general experience.

There was only a limited opportunity to explore with some of the infant children why their ideas had changed. Most children were unable to explain but some provided reasons of which the following is a representative example..

Interviewer: *'How do you know which things will let electricity pass?'*

Billy: Age 6 *'Cos you see the bulb light up.'*

Interviewer *'Why does that happen?'*

Billy *'Cos it's metal.'*

Interviewer: *'How do you know which things let electricity pass?'*

Danny: Age 5 *'They have all got metal'*

These excerpts show that it is possible for young children to develop the concept of metals and that one of the attributes of a metal is its ability to conduct electricity.

The intervention activities have produced some significant changes in understanding but since the pre-existing knowledge of many children was essentially correct, there was no substantial shift in their understanding. Those changes that did occur represent improvements in children's ability to differentiate non-conductors of electricity from conductors. The implication is that such an approach does not diminish any child's understanding and for some it has a positive effect.

Children were asked how they would test to see if an object would let electricity pass through it. This was done partly to see if they knew that a circuit was required and partly to test if they could represent the circuit that was needed. Children were encouraged to draw or write a response. This proved to be a difficult exercise for most children and consequently was not used with infant children who have substantial difficulty in accurate, presentational drawing let alone writing. Only upper juniors were really capable of this task and Fig 5.9.1 shows an example of such a response.

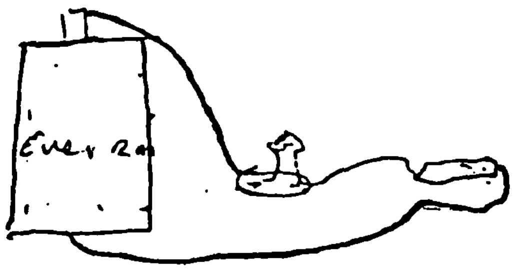


Fig 5.9.1: Simone Age 11-Drawing to show how to test materials for conduction

Many of the upper juniors used the 'circuit concept' to attempt to explain how to do this task.

'Make a circuit with a break in it then put the thing you are testing in the break.'

Responses were categorised into four categories: no attempt, some attempt, nearly correct and correct. The distribution of responses is shown in Table 5.9.5.

	Infants		*Lower Juniors*		*Upper Juniors*	
	Pre %	Post %	Pre %	Post %	Pre %	Post %
No Attempt	63	33	77	33	39	19
Some Attempt	37	55	17	44	29	32
Nearly Correct	0	11	6	11	18	24
Correct	0	0	0	11	14	24

(Rounding errors have occurred in some percentages)

Table 5.9.5: Percentage of children giving each category of response to question on how to test for conductors.

Changes for infants are significant at the 5% level and the data show that the trend in all cases was towards an increase in competency on this question. However only a small number of children were capable of correctly showing how the circuit should be constructed to test the material. This difficulty implies that their notion of a circuit may be specific to certain contexts and not easily generalised to unfamiliar situations.

5.10. The effect of more batteries on a circuit.

This item was used to explore whether young children held a model of batteries that included at least an intuitive recognition of voltage. A bulb was shown to children connected to two batteries in series. It was hoped that children who understood that more batteries would drive a higher current because they had a higher voltage, would have indicated this fact in their comments. The intervention had provided an opportunity for children to explore connecting circuits with more than one battery if they wished but this was not a specific activity that was recommended to teachers. Results are shown in table 5.10.1

	Infants (n=27)		Lower Juniors (n=18)		Upper Juniors (n=62)	
	Pre %	Post %	Pre %	Post %	Pre %	Post %
No Attempt	15	7	22	6	10	11
'Lights up'	59	74	5	17	50	45
'Be Brighter'	4	4	55	72	26	35
Other	22	15	17	6	15	8

Table 5.10.1: % of children by age groupings and their responses indicating the effect of more batteries on the brightness of a bulb.

The predominant response for infants and upper juniors was that the light will light up though there is a sizeable minority of upper juniors who indicate that it will be brighter. Rather strangely, the majority of lower juniors recognise that the bulb will be brighter which is inconsistent with the other two groups. A possible explanation for this anomaly lies in the small size of the lower junior sample (n=18). None of the changes were significant and an examination of the figures shows that the intervention has done little to change children's knowledge of the effects of more batteries.

5.11. Changes in Individual Children

5.11.1. Changes in ideas about constructing a circuit

The analysis so far provides an overall summary of the whole cohort but fails to provide any insight into the changes occurring for individual children. This chapter provides a view of some of the shifts in thinking that occurred for individual children which complements the description of the data by the networks.

The method is based on taking those items for which clear responses and categories of data are available and charting the changes that have occurred for each individual. This was done with the children's answers to items asking how connections would be made to bulbs and motors to make them function. The categories used have been those of the network i.e:- a) no response to the item; b) one connection shown between battery and lamp; c) two connections shown with two connections to the battery and one to the device; d) two connections shown with two on the battery and two on the device but not a correct answer; e) two connections shown correctly. Data for changes in children's representations for upper juniors are shown in Fig 5.11.1.1. The data are taken from the three items in each elicitation which asked children to show how they would connect the components so that they worked which gives a sample size of 186 for the upper juniors.

In the figure, the groupings of children's understanding are enclosed in circles. The arrows show counts for the number of children who have changed their response between the elicitation activities for that particular item whilst the number in the boxes, within the circles, shows the counts for the number of children who did not change their response.

The figures can be summarised into three groupings; (i) those which showed no change; (ii) those which show a change to a view which is indicative of progression- that is they changed from either no response to one connection for the bulb/motor or one connection to two connections though not necessarily scientifically correct; (iii) those which showed a less sophisticated representation. The chart shows clearly the fluid nature of children's responses which not only changed from one context to another, but also from one period to another. The evidence is that children's responses can regress as well as progress.

Data for lower juniors and infants were analysed in a similar manner and the figures are summarised in Table 5.11.1.1. Children who had moved from a response which shows 'one connection' to 'two connections - correct' or, from 'two battery connections -1 device connection' to 'Two battery connections-2 device connections' were assumed to be showing a response which showed an understanding closer to the scientific model. Such responses were judged to show evidence of an awareness of greater complexity showing an awareness of the necessity of two connections which must be made to different points on the battery and the device.

Table showing Individual Changes for Upper Juniors
(Possible number of responses = 186)

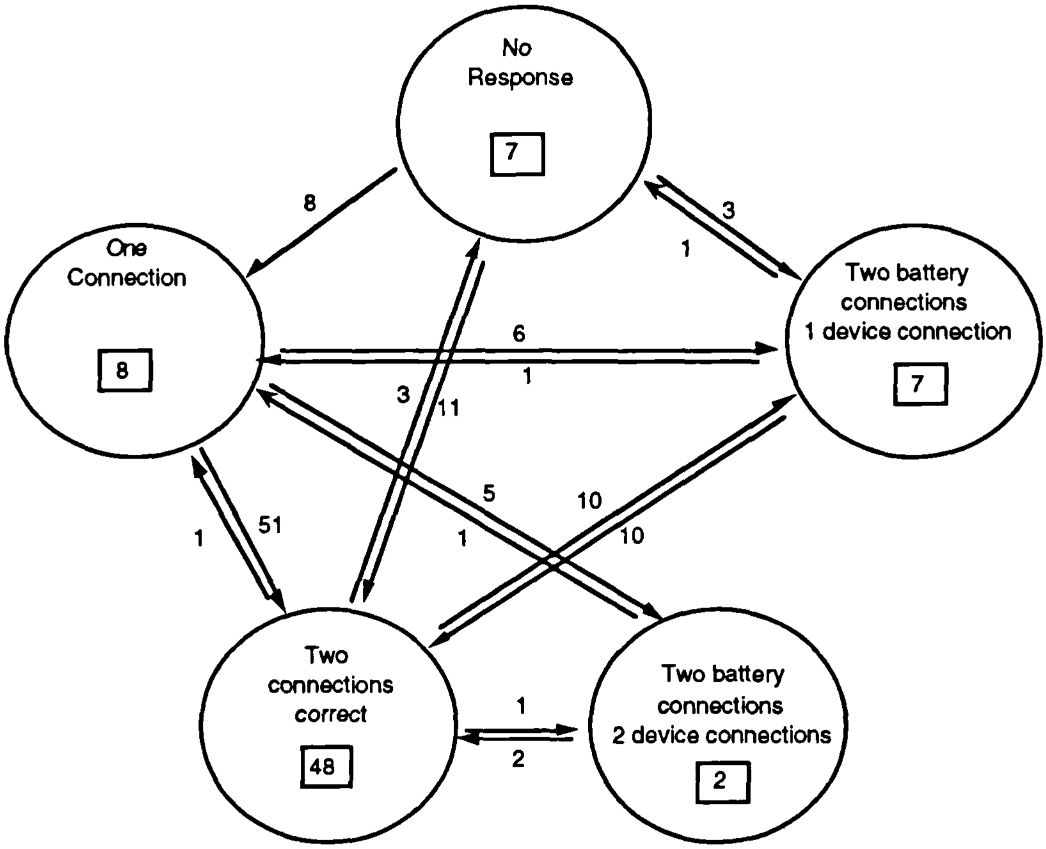


Fig 5.11.1.1 Schematic chart showing changes in children's responses from pre- to post elicitation on how to connect electrical items to a battery.

The most notable feature of these results is that the predominant trend was to more children providing a response in terms of two connections with relatively few children regressing. Those children which consistently hold the scientific view (or any other conception) are in a minority. The figures indicate that the predominant effect of the intervention was positive (Table 5.11.1.1).

A chi-squared test shows that there is a significant difference ($p<0.05$) for these responses as a whole between age groupings. Since the sample for the lower juniors was small, the significance was tested by collapsing the lower juniors with the infants. Most of the significance can be explained in terms of a larger number of upper juniors changing their thinking and a larger number already having a stable scientific conception.

	No Change Scientific Model	*No Change*	*Change to a response closer to the scientific model*	*Change to a response further from the scientific model*
UPPER JUNIORS	48	24	96	18
LOWER JUNIORS	22	9	16	7
INFANTS	2	27	43	9

Table 5.11.1.1. Summary of individual responses showing changes between elicitations to responses on connecting circuits (n=186).

The same method was used to look at individual changes exhibited by children in their understanding of the origins of electricity, the danger associated with electricity, the model of travel and the consistency of the responses that they provided.

5.11.2. The Production of Electricity

The four schematic groupings used for this analysis are shown in Fig 5.11.2.1 and the data for individual changes in children's responses to the origin of electricity are shown in Table 5.11.2.1. The response elicited from a child was assigned to one of the four categories above and then the process repeated for their response after the elicitation. From this it was then determined which of the categories shown in table 5.11.2.1 most appropriately described the change in their responses between the pre- and post - elicitation.

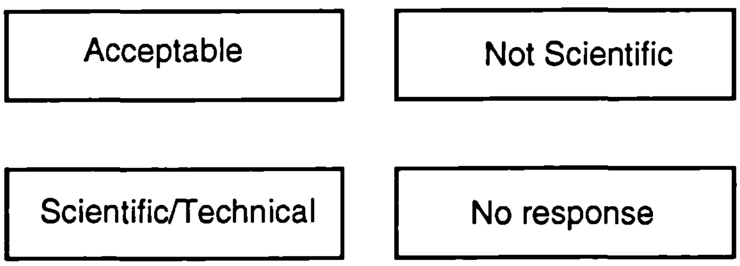


Fig 5.11.2.1: Schematic Categories used for analysing children's responses about the Origins of Electricity

The figures indicate that, for the majority of children, the intervention has had no clear effect on the response they provided to this item. Only a minority of children provide a response which could be said to be 'acceptable' e.g. that they indicate that electricity comes from 'power houses'. Not surprisingly, very few infants showed any knowledge of the origins of electricity. However, 30% of them did consistently provide a response which was scientifically or technically associated. A statistical analysis shows no significant differences between the changes from one age grouping to another. This suggests that children's ideas are relatively consistent and the intervention has had little effect in promoting change.

	No Change Response close to accepted idea	*No Change*	*Change to a response closer to the scientific understanding*	*Change to a response further from the scientific understanding*
UPPER* JUNIORS*	34	19	35	11
LOWER JUNIORS	28	28	16	28
INFANTS	4	48	37	11

Table 5.11.2.1: Percentage of individual responses showing changes between elicitations to a question asking where electricity came from.

* For tables 5.11.2.1 to 5.11.2.4 n=186 (Upper Juniors), n=54 (Lower Juniors) and n=81 (infants)

5.11.3. The Dangers of Electricity

For this analysis two groupings were used (Fig 5.11.3.1)

No Mention	Some Mention

Fig 5.11.3.1: Schematic Categories used for analysing children's responses about the Danger of Electricity

This aspect of electricity was not specifically addressed but was a prominent feature of the data. The data for the changes in individual children's expression of the idea that electricity was dangerous are shown in table 5.11.3.1. Again children's pre and post responses were coded to show whether they mentioned danger or not. The change in response was then assigned to one of the four categories shown in table 5.11.3.1.

These figures show that the majority of children made no mention of the danger associated with electricity and only a minority consistently mentioned this aspect on both occasions. The intervention had little effect on their association of danger with electricity apart from infant children where a large minority moved to a position where danger was not mentioned as a quality of electricity. This change was significant ($p<0.05$). The possible implication, is that the opportunity to explore electrical components and circuits in a context where there was no danger associated with any of the items, diminished early associations between electricity and danger for very young children- an example of the association between ignorance and fear.

	Danger mentioned	*Danger NOT mentioned*	*Change to a mention of danger*	*Change to no mention of danger*
UPPER JUNIORS	19	41	27	13
LOWER JUNIORS	17	66	11	6
INFANTS	11	33	19	37

Table 5.11.3.1: Percentage of individual responses showing changes between elicitations in mentions of the danger of electricity

5.11.4. How Electricity Travels

The groupings used for the analysis of individual changes in children's ideas about how electricity travels are shown in Fig 5.11.4.1.Children were asked in both the pre- and post elicitation how electricity got here and the data presented in Table 5.11.4.1 show how their individual responses to this item changed.

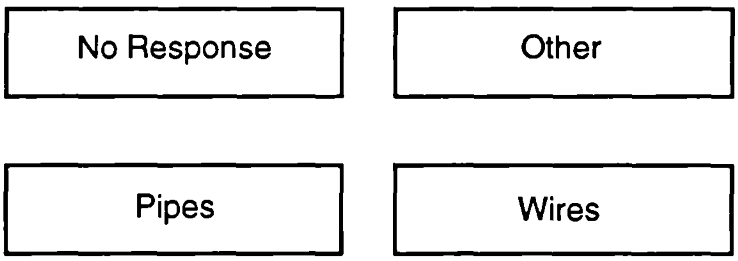


Fig 5.11.4.1: Schematic Categories used for analysing children's responses about the How Electricity travels.

	No Change Response close to scientific view	*No Change*	*Change to a response closer to the scientific view*	*Change to a response further from the scientific view*
UPPER JUNIORS	40	11	34	15
LOWER JUNIORS	33	25	28	22
INFANTS	4	31	48	15

Table 5.11.4.1: Percentage of individual responses showing changes between elicitations to a question asking how electricity gets here.

For the purpose of this analysis a change in response from 'no response' to one which indicated that electricity arrived in 'pipes', or a change from one which indicated that electricity arrived in 'pipes' to one which arrived 'on wires' was taken as evidence of an improved understanding by a child. There was a clear change in the number of children indicating that electricity arrives 'in' or 'on wires' from infants to lower juniors. Overall the intervention only affected a minority of children and statistical analysis shows that there is no significant difference between the distribution of responses across the age groupings. The change is positive for more children than it is negative, particularly for infants, but the data would indicate that the intervention has not been particularly successful in generating change in children's ideas apart from some limited success with infants.

5.11.5. Consistency of responses

Again a similar set of categories was used for analysing the changes that had occurred in the consistency of individual children's responses to similar questions asking how they would connect bulbs and an electric motors so that they would work. Responses were categorised into the four grouping shown in Fig 5.11.5.1 and then examined to see if they were consistent..

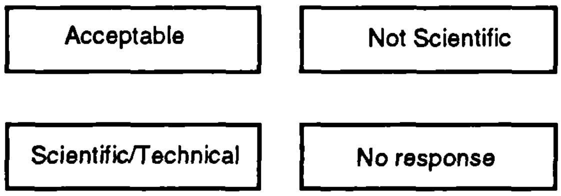


Fig 5.11.5.1: Schematic Categories used for analysing the consistency of children's responses showing how to connect electrical circuits.

Table 5.11.5.1, gives the data for the consistency of the responses provided by children

	No Change - consistent use of one model	No change in level of consistency	Change to a consistent response	Change to more consistency	Less Consistent responses	Response Rate Pre %	Response Rate Post %
UPPER JUNIORS	27	18	11	3	40	83	93
LOWER JUNIORS	17	22	17	6	39	83	87
INFANTS	22	34	0	4	41	54	80

Table 5.11.5.1. Percentage of individual responses showing changes in the consistency of responses provided by children about how to connect electrical devices.

(Rounding errors account for summations indicating that the figures are not consistent with 100%)

The total number of responses provided by children pre- and post-elicitation were 44 and 65 (infants), 45 and 47 (lower juniors) and 156 and 175 (upper juniors) - which represents a 17% increase overall though the most substantive increase was in the number of infant children prepared to provide a response to items about electrical devices. Overall, it is clear that one effect of the intervention, for a substantial minority of children, was to decrease the consistency of their response without any substantial increase in the number of responses. Only a few children showed a change to providing responses indicating the use of a consistent model. This evidence would support the idea that the response of many children was context dependent and that the wider range of experiences provided by the intervention has lead to the formation of models/ideas that were context specific, rather than the formation of any model which has general characteristics. Statistical analysis shows that there is no significant differences in the increase in context dependence between the age groupings.

Perhaps the most apt comment on the difficulties posed by the functional connections for an electric circuit has been made by Arons, who, in commenting on the perfomance of American college students on identical task, notes:-

> "When these students were given a dry cell, a length of wire, and a flashlight bulb and were asked to get the bulb to light, most started by (1) holding one end of the wire to one terminal of the cell and holding the bottom of the bulb to one end of the wire, or by (2) connecting the wire across the terminals (i.e., shorting the cell) and holding the bulb to one terminal. They showed no sense of the functional two-endedness of either the cell or the bulb....It took 20 to 30 minutes for some member of the group to discover, by trial and error, a configuration that lighted the bulb....Seven-year-old children, incidentally, when given the same task go through exactly the same sequence at very much the same pace."

Arons, (1990)

Arons' comments on his students' difficulties with the circuit concept and their prevalence from infant to higher education are an accurate reflection of the findings of this research and other work undertaken in this domain. The majority of children come to work on electricity with a concept of a circuit which can accurately be described as a 'source-sink' model, which is remarkably tenacious.

6: *The Processes of Life*

6.1 Introduction.

This chapter reports the research carried out into children's understanding of 'The Processes of Life' by the SPACE project and reported in Osborne et al (1993). The approach and methodology were similar to that carried out for the domains of 'light' and 'electricity' and a description of the general approach using a pilot and exploration phase, followed by elicitation of children's thinking, an intervention and post-elicitation can be found in section 3.3. Therefore this chapter, in common with Ch 4, 5 and 7 gives an overview of previous research which helped to form an interpretive framework for the data and to guide the formulation of interview protocols and tasks. Brief details are provided of aspects of the elicitation and intervention that are exclusive to this domain. However, the bulk of the chapter is devoted to reporting the data and findings of the research work.

6.2. A Review of previous research into Children's understanding of the Processes of life

6.2.1. Introduction

Processes of life such as growth, reproduction, movement, feeding, excretion, respiration and sensitivity are fundamental to any biological knowledge and the core concept of *living thing*. Studies of the development of the child's understanding of the processes of life have invariably focused on two aspects. Initial research examined animistic thinking by children and their concept of life and the criteria they deploy for establishing whether an object is 'living' or 'not alive'. Later studies examined the child's perception of the inside of the body and the processes of life themselves. Somewhat surprisingly most of the latter has been undertaken by those working in the field of psychology, nutrition and nursing and does not appear to be generally well known amongst science educationalists. Good summaries can be found in Carey (1985) and Mintzes (1984).

6.2.2. Living and Non-living

Perhaps the most well known initial studies undertaken by Piaget (1929) who established an explanatory framework based around the criterion of movement. Piaget's technique was to use the clinical interview and present the subject with an object and ask the question, 'Is it alive?' and, if the child's answer was 'Yes', he asked

'How do you know?'. From his results, he distinguished stages of development (Table 6.2.2.1) in the child's concept of what constituted a 'living object'.

Piaget's early work was developed into a standardised interview procedure by Russell and Denis (1939) and the area has been the focus of many replication studies, the most notable being that of Laurendeau & Pinard (1962). They tested 500 subjects between the ages of 4 and 12 and agreed with Piaget's conclusions apart from finding no evidence for a distinction between stages 1 & 2.

Stage 0	No Concept Random judgements or inconsistent or irrelevant justifications
Stage 1	Activity Things that are active in any way (including movement) are alive
Stage 2	Movement Only things that move are alive
Stage 3	Autonomous Movement Things that move by themselves are alive
Stage 4	Adult Concept Only animals (or animals and plants) are alive

Table 6.2.2.1: Stages of development in the child's understanding of living and non-living

Further studies in the field have generally given results which support this interpretation (see Jahoda (1958), Looft and Bartz (1969) for reviews). That this interpretation is open to question has come from studies which have adopted a different methodology and attempted to focus on what children conceive the 'attributes of life' to be and how these develop. Such studies have opened a rich field for exploration of which the research reported here merely represents a continuation.

One of the earliest studies was undertaken by Looft (1974) who asked children 'Does a frog breathe or need air?', 'Does a chair need food or nutrition?', 'Do automobiles reproduce or make more things just like themselves?' Looft also asked his subjects if the items used in the question were 'alive'. His important discovery was that although some students could correctly assign all of these objects to 'living' or 'not living', there was a lack of a full understanding of the attributes of life. Such work does not contradict the earlier studies and could be considered to be supportive in that it shows that children are clearly not using the 'attributes of life' as the prime criterion for deciding the issue of whether an object is alive/not alive. However, it does reveal a disparity between a child's and adult's concept of an animate object, and that children lack domain-specific biological knowledge.

A further study, by Smeets (1973), investigated whether children were capable of correctly attributing six life traits (die, grow, feel, hear, know, talk) to animate and inanimate objects. He found that these processes of life were often incorrectly attributed to inanimate objects.

Lucas et al (1979) identify a number of methodological errors in these studies. They argue that the increasing facility with age may just reflect an increasing familiarity with the everyday objects used. Secondly there are conceptual difficulties with the 'attributes of life' used which are strongly biased towards humans and ignore plants. The consequence is a tendency to over-rely on an anthropomorphic framework which would result in category errors.

Lucas et al's response was to use a technique which avoided some of these mistakes by showing children a black and white photograph of an 'object' which had been found on a beach. Children were then asked 'How could you find out if the object was alive? Write down as many ways as you can think of'. The study was done with 944 students from Grade 2 (age 6) to Grade 10 (Age 14). Their research identified five broad categories which students spontaneously used for establishing whether the object was living - expert advice, external structure, internal structure, physiological functions and behaviour. No children used one category only and although the work confirmed the use of the criterion of spontaneous movement found in earlier studies, the most revealing aspect was the lack of predominance of this criterion. At all grade levels, more than 40% of pupils suggested a criterion based on external structure. In addition, an increasing proportion at higher grade levels used a criterion based on internal structure and/or physiological functions. The authors argue that previous work has ignored the 'richness of children's responses to a highly complex question' and that the context of the data gathering can have an important effect on the nature of the response obtained.

Working in a different tradition, in which the conceptual development of children is studied from a psychological perspective, Carey (1985) chose to examine the development of children's understanding of alive/not alive and their accompanying biological knowledge between the ages of 4 and 12. Carey argues that the use of the framework 'alive', 'not alive' is simplistic forcing a categorisation which is not meaningful to the child. The inevitable failure to categorise is due to a lack of biological knowledge. Her data showed that such knowledge gradually improves between these ages which she believes results in a domain-specific restructuring, and it is this restructuring which results in the improvement of children's abilities to respond to the question of whether an object is alive/not alive. In a similar study to Smeets, she specifically chose unfamiliar animals e.g. aardvarks, dodos, garlic presses, clouds. and objects
She tested 9 subjects each from ages 4,5,7 and adults and found that at no age were

animal properties attributed to inanimate objects. Hence her results contradict the findings of Smeets (1974).

Her most striking finding was the under-attribution of animal properties to animals other than people, in particular breathing and eating, which led to a failure to attribute these properties to all animals. Carey postulated three mechanisms for children's reasoning:- deductive inference based on some narrow concept of an animal; the application of a definition which would involve checking for the component parts associated with the process i.e. mouth for eating, nose for breathing, and inductive projection based on comparison with humans. She concluded that, although all three types of reasoning contribute, the evidence was that the primary basis of their reasoning was the third mode - inductive projection. Her major claim is that her data showed that there was a major restructuring of domain specific knowledge of the child by the age of 10. This enabled the child to conceptualise the human body in terms of an integrated functioning of internal organs and perceive other living things in similar terms.

In summary, early studies would seem to have attempted to reduce the child's view of the world to a description which later work has shown to be simplistic. The evidence is that there are several facets to the criteria deployed by children, not least of which is their biological knowledge.

6.2.3: Human internal organs

The most well-known study is that of Gellert (1962) in which she asked 96 children, age 4 to 16, to list what they have inside them, where they thought the major organs are found inside the body, what the role of each is and what would happen if one lacked such an organ. The overriding conclusion of her study was that there was a significant development in their biological knowledge between children (age 5-8) and older children (age 9+). The former group came up with approximately 3 things inside people whilst the latter were able to list 8. The younger group predominantly think in terms of what they have seen put in, and coming out i.e. food and blood whilst the older group add a wide variety of internal organs. Another important finding was that when asked, "What do you think is the most important part of the body?", the younger group responded with external parts e.g. hair, nose, feet, eyes whilst by age 10, children respond with internal bodily organs.

Gellert also showed that young children's understanding of defecation is one which sees the process as one of social necessity, necessary so that we will not get too full or burst. Only when children reached the age of 13/14 did they see the process as the elimination of waste or noxious substances by the body.

Further studies undertaken since then have confirmed this analysis (Johnson & Wellman (1982); Contento (1981)). In particular what they show is a lack of understanding by very young children, age 5-6, of what happens to food. Most know that it goes to the stomach but imagine that it stays there unchanged or is broken into smaller bits. Contento's work showed a strong relationship between Piagetian stages and such understanding. All the children at a pre-operational level considered food to remain unchanged when eaten, whereas children at a concrete level recognised that food changes but the majority did not know how.

Gellert's study clearly showed that the heart was the first internal organ that children were aware of, partly because it has a clearly detectable presence in that it 'beats'. By the age of 10 or 11 well over half this age group realised that the heart is a pump and circulates blood around the body. Again very few of the younger children under 7 in Gellert's study had heard of lungs or could begin to explain their function. Only by the age of 10 did they show an understanding of their role in exchanging gases and the circulation of air/oxygen to the rest of the body.

Crider (1981) has attempted to place some kind of theoretical framework on these descriptive lists which one author has described as the 'conceptual ecology' of the classroom (Driver, 1989a). She argues that when the young child comes to know an internal organ, each is assigned a single function e.g. the lungs are for breathing. From such ideas the child moves to perceiving an inter-relatedness of the organs which are perceived as containers with channels connecting them. The final stage involves the development of a particulate understanding which sees matter such as food as being reducible to a microscopic level at which it can be transported around the body. Crider argues that this is achieved by the age of 11 for many pupils but in view of the research on children's understanding of the particulate nature of matter (Brook, Briggs and Driver, 1984) which shows that the majority of the children are incapable of understanding such an idea, this argument must be open to question.

Johnson & Wellman (1982) also conducted a study of children's understanding of the nature and location of the brain. Their study looked at what children perceived to be its function and what activities require a brain. In summary, they found that awareness of the brain as an internal organ begins at age 4 where its function is recognised for thinking. What was not recognised was that involuntary motor acts such as walking, coughing, sleeping required activity by the brain. Children of age 5 saw the brain as being autonomous from a whole range of body parts e.g. eye, mouth, ear, but by age 10 nearly 80% saw the brain as helping the body parts. Essentially young children see the brain as a mental organ which has no specific physiological function. Children's understanding of nerves consequently is very limited other than that they are an integral part of the body with no specific function. Only after age 9 were some children able to assign them a specific function related to conducting messages, controlling activity or sensing pain.

One notable point that emerges from Johnson & Wellman's study is the effect of instruction about the brain to a group of 11 year old children. Their research took place before this group studied a unit on the brain. They investigated their understanding after the unit had been taught and found that the teaching sequence had absolutely no effect on their learning.

6.2.4. Other Processes

The other two processes extensively studied are birth and death. The two most significant studies of birth are by Bernstein and Cowan (1975) and Goldman and Goldman (1982). Bernstein and Cowan classified children's progression into 6 levels of understanding from that of the youngest children, level 1, whose explanation for babies was that babies had always existed, to children at level 6, who explained conception in terms of the fertilisation of the egg and the combination of genetic material. Level 4, at which the child recognises that the 'seed' from the father is united with the egg from the mother, is the one that is independent of animism and artificialism. Goldman and Goldman's cross-cultural study of North American, English, Australian and Swedish children revealed that English children were significantly weaker at attaining a level 4 understanding by age 11.

North America	England	Australia	Sweden
80	63	87	97

Table 6.2.4.1: Percentage of children attaining a level 4 understanding of the process of reproduction by age 11. (Goldman & Goldman, 1982)

Carey argues that the data show clearly that young children see the production of babies only in terms of the intentionality of their parents and have no knowledge of the function of the body in the process. By age 10 they make a clear distinction between the role of the body and the role of the parents.

The problems posed by death in families and the effect on children have led to some very extensive research by psychologists. Again Carey (1985) summarises much of the wide-ranging literature. Psychologists essentially identify three phases. In the first stage (age 5 and under), children have no concept of the cessation of biological function and death is seen in terms of a separation which is neither final or inevitable. In the second stage, the child now recognises the finality of death but sees death as being caused by an external agent e.g. guns, knives, 'Father Death', poisons. In the final stage, which occurs for most children around age 9 or 10, death is seen as an inevitable biological process. Whilst death cannot be separated from the human and emotional perspective, Carey argues that it is the irreversibility of the process which leads to the emotional impact and that children's level of understanding of death by age 9/10 shows that they have developed the biological knowledge to appreciate the significance of death from an adult perspective as an irreversible process caused by the cessation of function of one or more organs.

6.2.5. Conclusions

Clearly the existing body of research in this domain is extensive, but as noted, not well known to science educators and much of it pre-dates the work of the 'alternative conceptions' movement. Many of the studies have attempted to place their findings within the context of a Piagetian developmental perspective i.e. pre-operational, concrete and formal. Carey (1985) argues that there is little to be gained by such a process because such a structure is a description of children's logic which fails to accurately interpret the nature of children's thinking and secondly it 'commits one to the claim that there is something which limits the understanding of digestion or the origin of babies.' Instead she develops a case that the evidence suggests a restructuring of domain-specific knowledge which enables a shift in conceptualisation of the processes of life.

6.3. The Research Programme

Classroom work on the topic of 'processes of life' took place over a relatively long period in the school year which can be summarised as follows.

Pilot Exploration	Sept 89
Pre-Intervention Data Collection	Oct 89
Intervention	Nov 89
Post-Intervention Data Collection	Dec-Jan 90

The pilot phase and the elicitation were conducted in a very similar manner to those for 'Light' and 'Electricity'. A full set of the questions used in the elicitations are provided in Appendix 6a and followed the principles outlined in section 3.3.

For some teachers, this was the third phase of the research work that had been conducted with their collaboration. This meant the principles and underlying approach to the intervention work had been reasonably well assimilated and that the teachers were able to work more independently within the general framework described in section 3.3.3. However, because some teachers were new to the project, and because they provided a focus for teachers to build on, a sample set of possible activities was prepared with teachers for their use (Appendix 6b). As usual, the work of the intervention was heavily influenced by the conceptual agenda of learning goals which were defined in discussion with the teachers after a consideration of the data obtained from the elicitation process.

6.4. Defining Learning Goals for 'Processes of Life'

By the time this phase of research began, the National Curriculum Order had been published(DES, 1989) and the framework of the research changed. The Order defined, in a set of attainment targets, learning objectives for children to achieve through the age range in a progressive, developmental fashion. Whilst the Order and their articulation of the targets within it are open to debate, they represented at the time, the standard objectives that many teachers would be using for their teaching. Hence the decision was made to adopt these statements as guidelines of what it might be reasonable for a child to be expected to know. This does not imply that the team necessarily accepted these statements as reasonable expectations but they did constitute a set of aims for many teachers and their children. Therefore the research set out to ask whether they were reasonable expectations.

The National Curriculum was defined in terms of a set of attainment targets and programmes of study. The attainment targets (Table 6.4.1) represented assessment objectives on a 10 point scale. An able infant is expected to achieve level 3 by age 7 whilst an average child would achieve level 2. A able junior should achieve level 5 by the age 11 whilst an average child level 4. The programmes of study (Table 6.4.2.) merely defined the set of experiences that should enable the attainment targets to be achieved.

The purpose of this list is to provide a framework or point of reference for the research where these statements represent a collection of ideas that children *may* develop by age 11. The principal difference between this research and earlier work on light and electricity, is that this is an externally defined list. Therefore, one of the subsidiary aims of the research was to examine to what extent, as a consequence of the experiences that were provided by this research programme, such ideas develop in children and at what ages?

Level	Attainment Target
1	Pupils should: • be able to name or label the external parts of the human body/plants, for example *arm, leg/flower, stem.*
2	• know that living things reproduce their own kind. • know that personal hygiene, food, exercise, rest and safety, and the proper use of medicines are important. • be able to give a simple account of the pattern of their own day.
3	• know that the basic life processes: feeding, breathing, movement, behaviour, are common to human beings and other living things they have studied. • be able to describe the main stages of the human life cycle.
4	• be able to name the major organs and organ systems in flowering plants and mammals. • know about the factors which contribute to good health and body maintenance, including the defence systems of the body, balanced diet, oral hygiene and avoidance of harmful substances such as tobacco, alcohol and other drugs. • understand the process of reproduction in mammals..
5	• know that living things are made up from different kinds of cells which carry out different jobs. • understand malnutrition and the relationships between diet, exercise, health, fitness and circulatory disorders. • know that in digestion food is made soluble so that it can enter the blood. • understand the way in which microbes and lifestyle affect health. • be able to describe the functions of the major organ systems.

Table 6.4.1: Attainment Target 1-5 of the English & Welsh National Curriculum (DES, 1989)

The programmes of study was as follows.

Key Stage 1[1]	Children should be finding out about themselves, developing their ideas about how they grow, feed, move and use their senses and about the stages of human development. Using suitable books, pictures and charts, they should be introduced to ideas about how they keep healthy through exercise and personal safety. Children should be introduced to the role of drugs as medicines.
Key Stage 2	Children should investigate some aspects of feeding, support, movement and behaviour in relation to themselves and other animals. They should be introduced to the functions of the major organ systems and to basic ideas about the processes of breathing, circulation, growth and reproduction. They should explore ways in which good health can be promoted in relation to their own daily routine, using a range of secondary sources chosen by the teacher. They should be introduced to the fact that while all medicines are drugs, not all drugs are medicines; and they should begin to be aware of the catastrophic effect on health resulting from an abuse of drugs. They should investigate the effects of physical factors on the rate of plant growth, for example, *light intensity, temperature and the amount of fertiliser*[2].

Table 6.4.2: Programmes of Study for the English & Welsh National Curriculum in Science at Key Stage 1 & 2.

Given such a framework of objectives, the intervention task was to develop activities which would assist the formation of a fuller understanding of these ideas in children. The activities were devised using simple materials familiar to children. Their primary role was to provide a focus for discussion of children's thinking and to challenge their existing ideas. Other considerations in designing activities were that the materials should be simple, easy to manipulate and safe to handle.

6.5. The Intervention

The elicitation gave a broad picture of the level of children's knowledge and understanding in this domain. Essentially, many children's knowledge of the body and

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1 The term key stage refers to the period of education. Key stage 1 is from age 5-7 (two years) and Key stage 2 is from age 7-11 (four years).

2 Italicised parts of this document are provided as exemplars

of its processes was limited to external features and there was therefore a need to provide opportunities to develop their understanding of its internal components and their function. Unlike some other aspects of science e.g. electricity and light, such knowledge cannot be shown or developed through empirical investigations which are a feature of much physical science. Hence, the intervention used a range of broad strategies which were available for teachers to use whenever judged appropriate. These can be described as a) sorting activities, b) discussion activities, c) modelling/making activities and d) investigations.

Sorting activities.

These activities require the active processing of information by children. Typically they would be provided with a number of cards. Each card would have a food on it and the children were asked to sort the foods into groups. Invariably, to start with children often sorted them into 'foods they liked' and 'foods they did not like'. The role of the teacher was then to encourage children to devise other ways of grouping the foods. One suggested activity for older children, was that food labels were cut off packets and then sorted by the categories of information on them to encourage children to explore the meanings of the data presented in food labelling. However, teachers were always asked to provide children with ample opportunity to explore their own approaches to categorisation.

Another use of sorting was to provide children with a set of cards, each with a part of the body the written on it e.g. ear, mouth, lungs and another set of cards with the function on e.g. for hearing, for chewing food, for taking in oxygen. Children were then asked to match the names on the cards with their functions as a group activity.

A third approach was based around the use of simple classification activities. Sets of objects were provided and children asked to sort them into living and non-living. Children used their own criteria to start with but each time they used one criterion, they were then asked to think of another. Older children were encouraged to use more complex forms of classification to derive a wider range of groups e.g. Does it move? Does it live in water? and they were encouraged to use a variety of computer programs which enable such classification.

Discussion Activities

Many of the sorting activities discussed previously were undertaken by groups and hence required discussion and communication between peers which encouraged both articulation of their own thinking and the exchange of ideas (Barnes, 1976).Wherever possible, activities were used that encouraged the use of this technique.

For instance, children were asked to discuss in groups such questions as 'How do healthy people look?' 'What do healthy people do?' and to produce a message for not so healthy people. In another activity, children were asked to draw a picture of what they thought was inside the body and then discuss each others' pictures and produce a group picture which they felt was most nearly correct. Further details of such activities can be found in Appendix 6b.

Modelling/Making Activities.
Models provide a tangible and concrete experience of objects which are not readily open to inspection such as the inside of the body. In one activity, children were asked to feel all their bones and then compare their experience with the representation shown on a cut out model of a skeleton. For older children, another cut-out was used where children were asked to place parts of the body on a large cut-out. Making posters of 'things that make us feel good' and 'things that make us feel bad' or large posters of 'energy foods' and 'body building foods' was also encouraged as a active means of enabling children to share and discuss their thinking.

Investigations
The general principle underpinning the SPACE programme was that children should be provided with an opportunity to design their own investigations with whatever equipment was easily available. In this domain, the range and scope for investigations is limited. However, appropriate investigations were suggested to teachers in the event of the children failing to devise an appropriate investigation or to supplement the activities devised by the children. Simple stethoscopes were made with plastic cups and rubber tubes. Pulses were felt and timed, and children were asked to investigate the location of muscles in their own body.

6.6. The Elicitation:

6.6.1 General structure

The data were gathered by working with groups of children, generally 4 in number, who were asked to write their answers to questions 1-7 (Appendix 6a) and all the questions that required any drawing e.g. a drawing of what is inside your body or a drawing of four things that they do to keep healthy. Responses obtained were then discussed with the children in individual interviews to obtain further clarification of their meaning and the children's answers annotated by the interviewer. A set of 9 objects/drawings were then presented individually to the child and the question asked "Is this .... living, once living or never living?". The child's responses were then recorded by the interviewer, transcribed and analysed.

6.6.2 Themes considered by the elicitation

The data collected explored five themes of children's understanding which were identified in the English & Welsh national curriculum (DES, 1989). These were considered to be:

a. *What choices and actions are required for healthy living?* These issues were explored by the use of Q1 and 2 (Appendix 6a); asking the children to draw four things to do with healthy living and to draw a healthy meal and an unhealthy meal.

b. *What processes are performed by components of the body?* This understanding was explored by Q 3, 4, 5, 6; asking what the function of the heart was and to add to an outline drawing to show what happens to food and drink inside the body.

c. *What knowledge of the body did children have?* Question 7 and the questions asking children to draw 'where the heart was' and 'what else is inside your body' were designed to explore children's factual knowledge and awareness of their own bodies.

d. *What weighting or association is given to the processes of life in the child's concept of 'living thing'?* This question was explored by the use of a set of objects which where shown to the child who was asked to state whether the object was 'living', 'once living' or 'never living'.

e. *What was the child's knowledge of plants and their parts?* Only one question was used to explore this aspect of their knowledge where children were asked to label a drawing. The limited exploration of this aspect was in part a reflection of the apparent emphasis within the national curriculum, and in part a reflection of the difficulty of exploring understanding in this domain and the priorities of the research which placed more emphasis on children's understanding of their own bodies and their maintenance.

Questions (a) to (d) were addressed through multiple items which enabled the possibility of exploring the consistency or lack of it which children used in their answers.

The data presented are those obtained from children who were present on all three occasions i.e. the elicitation, the intervention and the second elicitation. Full sets of data were obtained from 75 children in total. This consisted of 23 Upper Juniors in year 5 & 6 of their education, 23 Lower Juniors, in year 3 & 4 of their education and 29 infants in year 1 & 2 of their education.

In the rest of this chapter, the data are reported under headings defined by the questions above.

6.7 What choices and actions are required for healthy living?

Health education is a topic undertaken to varying degrees in schools and a focus of much attention in the media. Articles and features in popular magazines, newspapers and the media often address issues of concern in this domain e.g. smoking, dietary fibre, exercise. This concern has been reflected in the curriculum with a greater emphasis placed on the development of attitudes and knowledge in schoolchildren conducive to healthy living. One simple question that arises is whether it is possible for children to understand the causal relationship underpinning their choice of actions if they do not possess a basic knowledge of their organs and bodily systems. For instance, the reason for the importance of dietary fibre has little significance if a child has no knowledge of intestines. Similarly, the effect of smoking on the alveoli of the lungs leading to emphysema and other diseases is unlikely to be understood. Despite these limitations, there is undoubtedly an element of conditioning generated by constant exposure to arguments for actions and choices for living. The question then for this research was - to what extent had such arguments been assimilated by children, and to a lesser degree - to what extent were they understood?

The first question to explore this understanding was a question which presented children with a range of foods and asked them to ring those which they considered to be healthy. The foods were categorised by the researchers into three groupings - healthy, indeterminate and unhealthy (Table 6.7.1) and the pupils' responses analysed.

Healthy	Indeterminate	Unhealthy
Lettuce Apples Rice Juice Brown Bread	Bread Meat Potatoes	Chips Coke Burger Biscuits Sweets Crisps

Table 6.7.1: Table showing categorisation scheme used for analysis of Q1

Children's responses were then analysed and categorised on the basis of this schema and the table 6.7.2 shows the percentage of responses given in each category by the different groups of children.The data show that upper and lower juniors were clearly knowledgeable about which foods are commonly considered to be 'healthy' and 'unhealthy' since only a very small percentage of the 'unhealthy foods' were marked 'healthy'. The data also show the effects of the intervention were limited and only the upper juniors showed evidence of a more refined concept of what constituted a healthy food, by correctly categorising a greater percentage (87%) of the foods as 'healthy', and marking a smaller percentage (47%) of the indeterminate foods as 'healthy'. An analysis of this table using chi-square tests shows that from pre- to post-elicitation, this change was significant (p<.05).

Age Grouping	Healthy		Indeterminate		Unhealthy	
	Pre %	Post %	Pre %	Post %	Pre %	Post %
Upper Juniors (n=23)	75	87	62	47	3	2
Lower Juniors (n=23)	69	66	65	69	11	4
Infants (n=29)	77	75	79	78	34	22

Table 6.7.2: Total % of all the foods in each category indicated as being a 'healthy food' by each age group

The data for infant children would indicate that the concepts of 'healthy' and unhealthy foods are not so well formed as approximately one third (34%) of the 'unhealthy' foods were indicated as being 'healthy'. The difference between infant responses and lower juniors was highly significant (p < .001) both pre- and post-elicitation. Since infants marked many more of the unhealthy foods than lower juniors as 'healthy', this would possibly suggest that during this period that a process of differentiation and refinement of the functions of food occurs so that children recognise that 'you eat to live' is too simplistic and that some foods are essential or necessary for life, whilst others are unnecessary or can even have a negative effect. Thus the children's improved knowledge is enabling them to refine their conceptual understanding.

The general approach in designing intervention strategies was to devise activities that required *active processing* of information requiring children to articulate their concept to others or themselves. In this case, one of the activities recommended was a food sorting activity where children were asked to sort foods (or cards carrying the names of foods), initially using their own categories and then those suggested by the teacher.

The evidence is that such activities did not achieve their purpose of substantially improving their categorisation of foods. In the intervention activity, children tended to initially use categories such as 'foods they like', 'foods they do not like' and perhaps it is this categorisation that is remembered more than the categories of energy giving foods, body-building foods and healthy foods which were suggested by the teacher. Other possible explanations would be that this occasion would be the first time that children may have met such categorisations and their meanings may not have become self-evident from a limited encounter. What is notable is that children could identify healthy foods in over two-thirds of all the instances presented to them. This inevitably begs the question - why, if children are capable of recognising healthy foods, are they so reluctant to eat them?

The second question attempted to examine the wider implications of keeping healthy by presenting children with a selection of thirteen activities and asking them to ring those which are 'to do with keeping healthy'. These were deliberately chosen to represent a very broad spectrum of activities to fully explore the nature and extent of children's understanding. Once again for the purposes of the research, categorisation of the responses was undertaken using the following framework which was agreed by the researchers (Table 6.7.3).

Healthy	Intermediate	Unhealthy
Running Sleeping Feeling Happy Swimming Playing with Friends	Eating Arguing Laughing Reading	Watching Television Smoking Fighting

Table 6.7.3: Table showing categorisation scheme used for analysis of Q2

Table 6.7.4 beneath summarises the data showing the percentage of all responses for each category indicated as being 'healthy' by each age group i.e. 64% of all the possible 'healthy' responses were marked healthy by the Upper Juniors

Age Grouping	Healthy		Indeterminate		Unhealthy	
	Pre %	Post %	Pre %	Post %	Pre %	Post %
Upper Juniors (n=23)	64	71	41	42	0	4
Lower Juniors (n=23)	63	71	43	53	1	5
Infants (n=29)	79	77	64	62	16	14

Table 6.7.4: Total % of all possible responses in each category (healthy, indeterminate and unhealthy) indicated as being 'to do with keeping healthy' by each age group

Undoubtedly the most remarkable feature of this table is the consistency of the responses pre- and post-elicitation. There were no significant changes for any of the categories and clearly the intervention has failed to alter any notions children may have had of what constitutes a healthy activity. What the data do show is that children were aware, from an early age, that the activities of smoking, fighting and watching television can not be considered healthy activities as very low percentages of children across all age ranges marked these categories of response. Conversely two thirds to three quarters of all the choices categorised 'healthy' were correctly indicated as 'healthy' with little variation between the age groups.

The only significant ($p<.01$) variation found in response was between the infants and the other two age groups prior to the intervention. The former correctly indicated more of the healthy responses but also marked more of the 'unhealthy' and 'intermediate' responses as being 'to do with keeping healthy'. A possible explanation is that the significance can be explained by a tendency of infants to ring any response when unsure about the healthiness of the suggested activity in response to the question. Thus the data would not support the inference that they have a better understanding and knowledge of what constitutes a healthy activity.

The third question to address this matter was the one which asked children 'to draw four things which are to do with keeping healthy.' Children's drawings predominantly fell into two categories and in addition, a range of minor categories which were more infrequently shown. The major categories were considered to be 'food and drink' and 'exercise and sleeping'. Minor categories were 'drugs', 'smoking' , 'vitamins' and a wide variety of other activities associated with keeping healthy. Food and drink was divided into three groupings of 'healthy', 'indeterminate' and 'unhealthy' following the definition shown in Table 6.7.3.

The data for this question were collected by ticking a category for each drawing judged appropriate to a category and the results are shown in table 6.7.5. Children who gave many drawings in one category are only counted once on this table whilst children who gave drawings in more than one category are counted twice or more. Thus the data in the table reflects the breadth of understanding shown by the whole group rather than the knowledge of individual children

Overwhelmingly, pupils of all ages drew food in response to this question. Fig 6.7.1 shows a typical response. The second most popular choice was some indication of exercise or sleeping as being a healthy activity. It was notable though that the activities tended to be 'adult' ones i.e. jogging, weight-lifting which would suggest that their knowledge was possibly a reflection of media influence. Exercise was only mentioned by a minority of the infants as opposed to a majority of the lower and upper juniors. Relatively few other activities were mentioned by children of any age group. Those that were predominantly watching TV and drinking. The justification for the former tended to be that 'it gave you peace and quiet' and 'you learn things'.

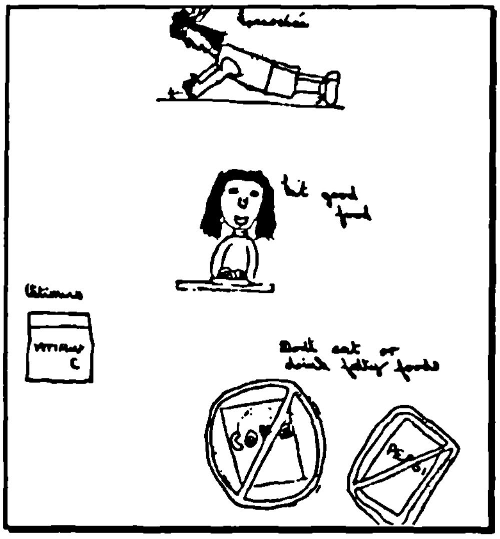

Fig 6.7.1. Response of a child (age 10) to question asking them to draw activities which were healthy.

The responses to this question are similar to those discussed previously. There is little variation between any of the age groups either before or after the elicitation. The only significant variation ($p<.01$) was between infants and the other two groups. The latter's responses contained more diagrams indicating that exercise and sleeping were activities that kept them healthy. This feature of the data was still present after the intervention.

Category	Infants (n=29)		Lower Juniors (n=23)		Upper Juniors (n=23)	
	Pre	Post	Pre	Post	Pre	Post
Food						
- Healthy	23	23	22	14	20	18
- Indeterminate	0	1	-	2	-	1
- Unhealthy	3	5	-	-	-	-
Exercise & Sleeping	4	7	14	20	13	19
Drugs/Medicine	1	-	-	-	1	6
Smoking	-	-	-	-	1	4
Vitamins			-	-	3	-
Other						
- drink	-	-	6	2	2	-
- brush teeth	-	-	4	2	-	-
- washing	-	-	-	3	-	-
- watching TV	-	6	2	-	-	-
- going to toilet	1	-				
- playing	-	1				
Unclassifiable	3	-	-	-	0	0

Table 6.7.5: Total numbers of children giving drawings in each category

The intervention had only one significant effect ($p<.05$) in increasing the number of lower juniors who indicated exercise and sleeping as being an activity to do with keeping healthy. The numbers for the variety of 'other' activities are too small to assess their significance. The picture that emerges is one that is consistent with the answers to previous questions with little variation of response as a consequence of the intervention.

The final approach that was used to explore children's understanding of the choices and actions necessary for healthy living, was to ask children to draw a 'healthy meal' and an 'unhealthy meal'. Children were given a sheet of paper with an outline of two plates on it. One was labelled 'healthy' meal and the other labelled 'unhealthy' meal. Data were then collected of the types of food indicated. In all, 31 foods were drawn or mentioned by children. These were vegetables, carrots, peas, fish, tomatoes, potato, meat, lettuce, chips, fruit, hamburgers, bread, eggs, drink, rice, spaghetti, bacon, beans, brown bread, cake/biscuits, cheese, chicken, cod liver oil, cornflakes, milk, orange juice, sausages. Table 6.7.6 beneath shows the foods mentioned by more than 25% of the children for each group in either the pre- or post-elicitation.

With the exception of the infants, these tables reveal that children have a clearly defined notion of what constitutes a 'healthy' meal. Carrots, vegetables and peas were the foods that predominate in the thinking of upper and lower juniors and it was notable that anecdotal evidence would suggest that it is these foods which are generally not appreciated by children. Whilst there was some variation between pre- and post-elicitation and some changes were significant, it would be difficult to ascribe a causal mechanism to the change in the choice of one 'healthy' food compared to another. A more important point is that for the both lower juniors and upper juniors, 5 out of the 6 foods were mentioned by more than 25% of all pupils both pre and post-elicitation.

Upper Juniors: Table 6.7.6a

Pre		Post	
Carrots	78%	Carrots	57%
Veg	61%	Peas	48%
Lettuce	52%	Lettuce	43%
Fish	35%	Rice	39%
Peas	26%	Meat	30%
Tomatoes	26%	Veg	26%
Meat	17%	Tomatoes	17%

Lower Juniors: Table 6.7.6b

Pre		Post	
Veg	74%	Carrots	78%
Carrots	70%	Peas	70%
Peas	65%	Veg	39%
Fish	48%	Fish	39%
Tomatoes	26%	Potatoes	30%
Potatoes	22%	Tomatoes	22%

Infants: Table 6.7.6c

Pre		Post	
Chips	41%	Fish	45%
Bread	41%	Fruit	31%
Fish	34%	Vegetables	28%
Fruit	34%	Peas	21%
Peas	28%	Bread	14%
Vegetables	17%	Chips	14%

Table 6.7.6 (a), (b) & (c) showing the principal foods indicated as being 'healthy' and the % of each group doing so.

These data would suggest that children of this age had developed a well-defined set of criteria of what constituted a healthy food prior to the intervention. For the infants, 3 out of the 6 most-often mentioned foods are identical before and after the intervention. More interesting is that only two of their foods, fish and peas, were mentioned by upper and lower juniors. Children in the latter two groups were different in that they did not mention bread and chips so frequently. From a health education perspective, this clearly constitutes an improvement in children's understanding and is evidence of the value of such intervention work with children of this age. Perhaps surprisingly, infants were the only group to regularly mention fruit as a 'healthy' food.

A similar analysis was performed for the responses to the other half of the question which asked children to draw what they considered to be an 'unhealthy' meal.

Upper Juniors: Table 6.7.7a

Pre		Post	
Chips	83%	Chips	100%
Hamburgers	48%	Hamburgers	78%
Eggs	43%	Sausage	35%
Sausage	26%	Cake	26%
Cake	4%	Eggs	9%

Lower Juniors: Table 6.7.7b

Pre		Post	
Chips	83%	Chips	78%
Hamburgers	57%	Sausage	48%
Sausage	26%	Hamburger	43%
Eggs	26%	Eggs	30%

Infants: Table 6.7.7c

Pre		Post	
Sweets	79%	Sweets	55%
Eggs	34%	Chips	31%
Cake	34%	Eggs	7%
Chips	28%	Cake	7%

Table 6.7.7 (a), (b) & (c) showing the principal foods indicated as being 'unhealthy' by children and the % indicating so.

Again, the notable feature of this data was the distinction between the infant group and the other two groups. Upper and lower juniors consistently indicated the same foods i.e. chips, hamburgers and/or sausages as being 'unhealthy', whereas the food which featured predominantly for infants was sweets. Two points can be made about this data. Firstly that infants concept of a meal permitted the inclusion of sweets. More importantly though, it is clear that whilst the infants had a notion of what was unhealthy, their concept of this was different from that of lower and upper juniors. This would suggest that over this period, concepts of food and their value are in some process of development. Given that children appear to clearly appreciate what was unhealthy food and yet, continue to eat it, this phase of development would possibly be the appropriate moment to intervene and develop a better scientific understanding and more sensible attitude to food. Unfortunately the evidence gathered from this study does not sustain such a hypothesis but such a change may possibly not have occurred because of limited treatment of the issue by the intervention.

In summary then, the research provides a clear picture that these children from the age of 5 upwards were clearly aware of the role of exercise and the choice of food in sustaining a healthy lifestyle. In many areas, there was evidence to suggest that children had some understanding of such concepts prior to the intervention. This would in part, explain the lack of significance in any of the findings since the knowledge explored was already internalised by children. The origins of this knowledge were not explored but given that these ideas are a regular theme of much advertising, it is not unreasonable to suggest that much informal education occurs through the media.

6.8. What knowledge of the body did children have?

Children's understanding of the processes of life will be limited by their biological knowledge. For example, a child who does not understand that the body contains lungs made of a spongy tissue which enables the interchange of gases with the blood is unlikely to see respiration as anything more than the act of breathing. Therefore science education will need to develop an awareness in children of a range of internal organs and their function at an early stage to facilitate their understanding of these processes.

In this research, children's biological knowledge was explored through three questions:- one which looked at the range of locations in which children could identify muscles, one which looked at children's idea of the location of the heart and another which asked children to add to an outline of the body, what they thought was inside.

The first question asked 'Where in your body are muscles?' and the data obtained are as shown in Table 6.8.1.

	Infants		Lower Juniors		Upper Juniors	
	Pre %	*Post* %	*Pre* %	*Post* %	*Pre* %	*Post* %
Arms	86	79	83	78	70	70
Legs	69	59	65	74	65	74
Fingers	21	0	0	26	0	43
Feet	3	3	0	22	0	22
Neck	7	0	13	17	0	13
Belly	10	0	0	13	17	13
Toes	0	0	0	0	0	17
Jaw	0	0	0	4	4	4
Wrist	0	0	0	4	13	0
Chin	3	0	0	0	0	0
Elbow	3	0	0	9	4	4
Heart	3	0	0	9	0	0
Body	7	0	0	0	0	0
Shoulders	3	7	0	13	4	9
Back	0	0	4	9	13	9
Chest	0	0	0	4	4	13
Face	0	0	0	4	4	0
Everywhere	0	24	4	9	13	35
Other	3	3	4	9	9	17
No response	3	3	9	0	0	0

Table 6.8.1: Percentage of children mentioning the specific location of muscles in the body.

The picture that emerges is one where the majority of children perceived muscles as being in arms and legs but only a small minority of responses indicated that muscles could be in other parts of the body. The general trend of the intervention was to improve the awareness of muscles in other parts of the body with a significant ($p<0.05$)

increase of the number of infants who stated that muscles were to be found everywhere in the body. This was accompanied by a significant decrease in the number of infants indicating that they were to be found in their fingers. Otherwise none of the changes was significant.

The data clearly define the limits of these children's knowledge and reinforce the notion that these children's knowledge of biology was limited to those aspects of the body for which there is an easily accessible direct experience. Muscles in the arms and legs can easily be sensed and felt, hence the readiness to state that this is where muscles are found. Muscles in other parts of the body are not so self-evident and their relation to movement was not appreciated by many of these children.

The next question to explore children's biological knowledge was one which asked children to draw (on an outline of the body) a picture of where there heart is. This question was chosen as it was felt that the heart is one internal organ which children are familiar with from a young age. Hence it was thought to be of interest to see what conception they held of this organ, its function and its location. The function was considered by a separate question which asked 'What does your heart do?. The data were tabulated in a network (Fig 6.8.1) in order to explore the relationships that may have existed in children's mind between the function, location and size.

Examining the data several clear points emerge. Firstly the overwhelming majority of children initially thought that the heart has a traditional valentine shape. The percentages holding this view are shown in Table 6.8.2.

	Infants		Lower Juniors		Upper Juniors	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Valentine Shape	83	80	74	48	65	35

Table 6.8.2: Percentage of children holding particular conceptions of the shape of the heart.

However, the effect of the intervention was to diminish the number of lower and upper juniors holding this idea to a minority. Whilst the size of the change for lower juniors approaches significance, it was only significant ($p<0.05$) with the upper juniors. The other positive effect of the intervention, also significant ($p<0.05$), was the increase in the number of lower juniors who indicated that the heart pumps blood.

The Heart		Infants Pre	Infants Post	L.Juniors Pre	L.Juniors Post	Upper Juniors Pre	Upper Juniors Post
Location	Correct	7	14	3	5	2	1
	Abdomen	10	7	2			
	Elsewhere						
	Left Body	4	5	17	17	18	21
	Right Body	7	4	1	1	3	1
Shape	Heart Shape	25	24	17	11	15	8
	Other	4	6	6	12	8	15
Size	Too Large	14	17	7	6		5
	Approximate	15	13	16	16		18
	Too Small				1	1	4
Function	Beats	20	17	14	3	2	15
	Pumps Blood	1	2	3	11	17	3
	Keeps us alive	1	1	2	5	1	
	Helps us to breathe	3	4	3	2	3	1
	Other						
	No Response	4	6	1	2		

No response at all 1

Fig 6.8.1 Network showing children's responses to questions about the Heart

A change in the numbers indicating that the heart pumps blood was not observed for upper juniors as the majority of these children gave this response in the pre-intervention elicitation. This difference between the two groups in the pre-elicitation phase is significant ($p<0.01$). This may be indicative that this change in understanding of the heart would have developed in time anyway. The effect of the intervention was simply to accelerate the change.

The other significant ($p<0.05$) difference prior to the intervention was between the infants and the lower/upper juniors. A large number of the former located the heart centrally in the abdomen. Only a very small number of the latter group indicated such a location. Interestingly, more infants indicated that the heart had a central location pre- and post-elicitation than any of the other two groups. The reasons for this were not explored and the only surmise is that children of this age, sense the heart as being central, but cultural messages eventually predominate in a situation where the object in question is not available for inspection.

The picture that emerges from the data is that the overwhelming majority of children see the heart as a valentine shaped object, located on the left of the body with a size which is approximately similar to its real size. Their conception of the function varies but none were able to articulate a view more comprehensive than a knowledge that it 'pumps blood'.

Whilst the origin of this conception of its shape can be ascribed to a wide range of the media, where it is reinforced daily, there is a need for primary science education to recognise the prevalence of this idea and provide children with the scientific view.

The final question which considered what knowledge children had of their own bodies was one where they were asked to add to an outline and 'draw a picture to show what else is inside your body'. Two contrasting responses are shown in the Fig 6.8.2 & 6.8.3.

Fig 6.8.2 shows a detailed biological knowledge with the organs drawn approximately to size and placed in the correct position of the body. Very few children were capable of providing such an answer. In contrast, Fig 6.8.3 shows a very limited understanding with only two parts drawn, neither of which is the correct shape or correctly placed. These drawings are shown to exemplify the range of answers which can be produced by upper junior children.

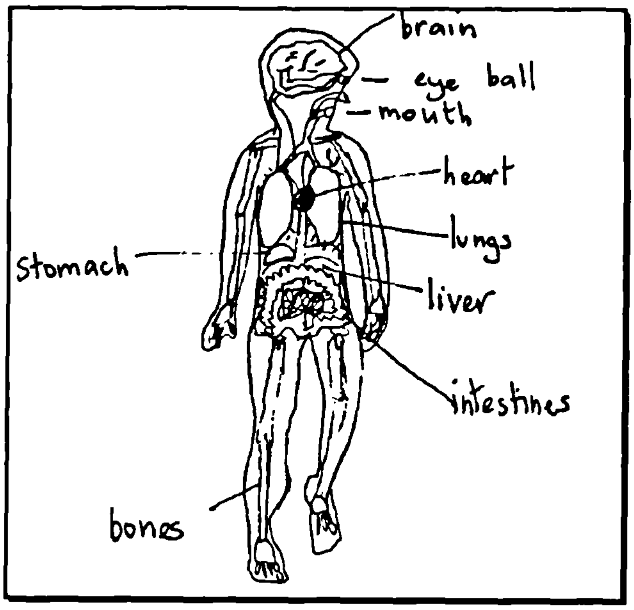

Fig 6.8.2: Child's[3]-(age 10) drawing of what he thought was inside his own body

An examination of the data in table 6.8.3 shows that the three internal parts of the body shown predominantly by all children of all age ranges were the heart, bones and the brain (with the exception of infants prior to the intervention). The average number of organs shown increased across the age range and between the pre- and post elicitation for both infants and lower juniors which would indicate that the intervention has had some success in improving children's knowledge (Fig 6.8.4).

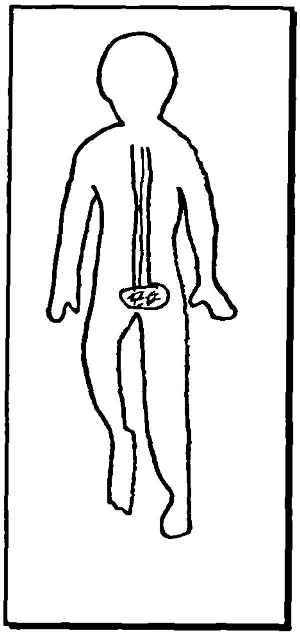

Fig 6.8.3: Child's-(age 10) drawing of what she thought was inside her own body

3 The annotations to this diagram are those of the interviewer.

	Infants		Lower Juniors		Upper Juniors	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Blood	9	6	3	3	1	1
Bones	25	24	13	10	12	9
Heart	16	20	18	20	19	18
Stomach	10	9	6	5	12	4
Belly	5	6	1	2	2	0
Brain	1	12	9	10	18	16
Kidney	1	0	1	3	5	10
Liver	0	0	0	2	3	4
Lungs	0	8	5	9	11	14
Windpipe	0	6	4	8	10	9
Bladder	0	0	0	0	1	2
Other	0	1	1	1	4	4
Veins	1	4	5	8	8	7
Intestines	0	1	0	1	3	8
Guts	7	5	2	6	0	1
Muscles	4	0	1	0	5	7
Food	0	0	1	0	0	0
Eyeball	0	0	0	0	1	0
Nerves	0	0	0	0	0	0
Totals	79	102	70	88	115	114
Av No	2.72	3.52	3.0	3.8	5.0	5.0

Table 6.8.3: Numbers indicating Internal Organs present in the body

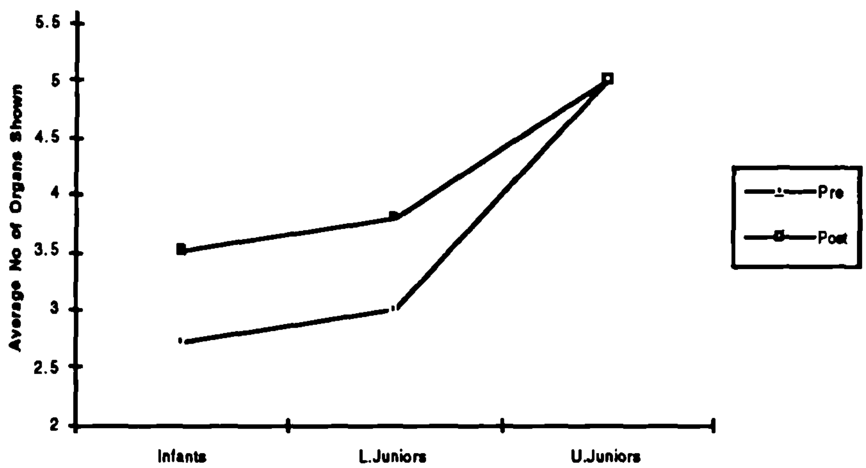

Fig 6.8.4: Average number of internal parts of the body shown by each age group, pre and post-elicitation

A similar trend was found by Gellert (1962) who also found that the most frequently named parts were bones, blood, the heart and brain. Her test was slightly different in that she asked children to name parts of the body rather than draw them. The difficulty in representing blood in drawings may account for the absence of blood in the data shown above.

This data would also confirm Carey's (1985) evidence that children's biological knowledge develops between the ages of 5 and 11. The effect of the intervention was positive for both the lower juniors and the infants but had no effect on the upper juniors. It is possible that the average number of body parts indicated by upper juniors represents a plateau which is not crossed until several years later.

Another index of the improvement is the number of children mentioning three or more organs (Table 6.8.4)

Age Range	No of Children	
	Pre	*Post*
Infants	7	10
Lower Juniors	8	10
Upper Juniors	11	12

Table 6.8.4: No of children indicating 3 or more organs/parts of the body.

With reference to particular parts of the body, the only significant change after the intervention was the number of infants indicating the presence of the brain ($p<0.01$) and lungs ($p<0.01$). both of which increased. Again it is notable that prior to the intervention, infants differed significantly from upper and lower juniors whilst afterwards they did not. This would suggest that the effect of the intervention has been to accelerate a natural occurring development in children's biological knowledge.

6.9 What processes are performed by components of the body?

6.9.1. Nutrition and the purpose of eating

This question was explored through a range of items. In essence the question is a superordinate one to the one that asks 'What are the parts/organs of the body?', since the processes undertaken by the body can only be explained by a child when he or she has a knowledge of its components and their interactions. Hence breathing (gaseous exchange) is a process where the structure of the lungs enables oxygen, a component of the air, to diffuse into the blood stream in the many capillaries which are found in the lungs. Whilst such an answer would not be expected from a primary age child, it illustrates the point that processes are descriptions of interactions and dependent on a basic description of the ontological nature of the body.

The research chose to examine children's understanding of the process of digestion and respiration. The process of sexual reproduction was avoided because of the difficulties of conducting research in this area with young children, and the concepts of growth and excretion were explored through asking children whether they thought a range of objects were alive, not alive or once living.

The first question asked of children was simply 'Why do you need to eat?'. The question elicited a range of straightforward answers which are shown in Table 6.9.1.1. These responses indicate that the children saw eating simply as a life support mechanism in broad terms, the predominant response at all ages being that food is necessary 'to stay alive'. Only four responses from upper juniors indicated that there is any component of food which is essential for body maintenance i.e. provides vitamins or helps your heart. The data show no evidence that there has been any significant change as a consequence of the intervention, though it may be that the question is in itself broad and failed to elicit the specific discussion of the components of food and their function.

	Infants		Lower Juniors		Upper Juniors	
	Pre	Post	Pre	Post	Pre	Post
Stay alive	11	9	7	6	10	13
To grow	8	11	8	7	6	7
To keep fit/strong	7	5	5	12	7	8
To keep healthy	8	8	7	0	8	5
To provide vitamins	0	1	1	0	1	2
The food helps your heart	0	0	0	0	0	2
Other	0	1	0	0	0	0
No response	1	2	1	2	0	0
Total number of responses	35	37	29	27	32	37
Mean number of responses per child	1.2	1.3	1.3	1.2	1.4	1.6

Table 6.9.1.1: Data showing number of each type of response by children to the question 'Why do we need to eat?'

The most notable feature was the remarkable similarity across the ages. A possible explanation is that these children are operating with a phenomenologically intuitive knowledge based on simple commonsense mechanisms i.e. that you need food/blood to keep you alive. It would suggest that children's vitalistic explanations were seen by them as being comprehensive and adequate, and essentially are correct. In fact, it can be argued that any better understanding of the processing of food and the function of blood requires an appreciation of the particle nature of matter and the transformation of substances. Neither of these concepts are generally addressed in primary science and, some (Shayer & Adey, 1981) would argue are not available to the cognitive processing of such children.

6.9.2. The role of blood and its circulation

The next questions attempted to explore what children saw as the function of blood and how it moved around the body. Children were asked 'What does blood do?' which was followed by the question 'How is the blood carried around the body?'.

Responses to questions about the purpose of blood and how it is carried around the body were more mixed and complex. At a basic level, blood was described as necessary 'to keep you alive' by both infants and upper juniors, but surprisingly not by lower juniors. A greater level of understanding was possibly shown by those children who indicated some knowledge of a circulatory process by stating that blood moved or ran through the body.

The latter idea was held by a reasonable minority of children of all ages. However, for approximately a third of all pupils, the question proved too difficult and no response was obtained. Some of the other responses obtained to this question give a glimpse of some of the ideas, some of which are quite logical, that children can hold about the purpose of blood.

It makes you stand up	Anthony - age 8
Keeps your skin clean	Susan - age 8
It lubricates the joints	Andrew - age 10
It runs good food around the body after it has been digested.	Edwin- age 9

The final response above approximates most closely to the scientific view but was expressed rarely by children.

Children's ideas about how blood is carried around the body, showed a range of thinking. There were a number of younger children who tended to think that blood moved itself or that body movement helped it to move.

When you walk and do things	Dean - age 5
It moves itself	Tumseela - age 5

It moves around when you wiggle Kathy - age 6

The latter notion carries with it the view of the body as an empty vessel around which blood sloshes. Many lower and upper junior children mentioned the veins in such responses and this shows a greater biological knowledge.

It goes through your veins Dustin - age 6

Interestingly, the term 'arteries' was never mentioned by children and this could possibly be a reflection of the lack of everyday use of this term.

The responses to these two questions were analysed using a network (Fig 6.9.2.1 and Fig 6.9.2.2) and the data show that very few children were incapable of providing any response at all to these questions, though many only attempted to answer one rather than both. Most children that attempted to provide an answer did so in general terms - blood is needed to keep you alive or healthy, or it moves around the body. The latter answer could be considered a more sophisticated answer in that it recognises that blood is a fluid which does circulate.

Children's answers to the question about how blood is carried around the body showed that some children had greater awareness of specific parts i.e. the heart or veins/tubes.

	Infants		**Lower Juniors**		**Upper Juniors**	
	Pre	Post	Pre	Post	Pre	Post
% of children mentioning heart or veins/tubes	31	31	56	74	61	65

Table 6.9.2.2: Percentage of children mentioning heart and/or veins

The data in Table 6.9.2.2 show that there was little change as the result of the intervention as none of the changes were significant. Again, there was a significant distinction between infants and lower juniors/upper juniors. The intervention did improve the biological knowledge of these two groups though only marginally in the case of upper juniors. The major difference existed prior to the intervention and would support the case that there was some development in children's biological knowledge during the transition from age 5/6 to age 8/9 and this is reflected in the data.

A more detailed examination of the data shows that only two changes were significant as a result of the intervention. At the 1% level of significance, the intervention had the effect of substantially increasing the number of lower juniors who said that the heart was responsible for circulating blood around the body and the number of upper juniors who expressed the idea that blood runs around the body. At the 5% level of significance, there was a corresponding decrease in the number of upper juniors who expressed the view that the function of the blood was to keep you alive. None of the other changes were found to be significant.

The other analysis of the data undertaken to these responses was to examine how many pupils expressed an answer which gave both a mechanism for the circulation of the blood, and a function or purpose for the blood in the body (Fig 6.9.2.2). In each case where a response was provided, it was coded as being correct or incorrect from a scientific perspective. Thus responses that said that the heart made the blood go round or that the blood moved through veins were coded as being a correct indication of the mechanism of circulation. Similarly a response that indicated that blood moved around the body was taken as a correct indication of purpose of blood. In making the latter categorisation, it is assumed that this level of knowledge shows an awareness that the blood is transported to all parts of the body. Responses that stated that the function of the blood was to keep you alive were termed incorrect on the basis that such a general statement failed to show any awareness of what might be happening internally at the microscopic level within the body.

The data show that the majority of infants and upper juniors gave a response which indicated both a mechanism and purpose for the blood. Only in a small minority could both of these be considered to be correct. Most of the other responses provided a mechanism or a purpose but not both. Only a few children gave no response whatsoever. An analysis of the data show that there were no significant changes as a result of the intervention.

			Infants		Lower Juniors		Upper Juniors	
			Pre	Post	Pre	Post	Pre	Post
Blood and its circulation	Knowledge of Blood – Function	Keep you alive/healthy	10	6	2	4	10	4
		No response	7	4	7	7	5	4
		Moves/runs through body	7	13	5	7	2	12
		Goes to heart/stomach	1	1				
		Comes out when cut	1	0		1		
		Other	1	6	5	2	4	2
	Knowledge of Blood – Circulation	Moves itself	5	1			2	3
		By Veins/tubes	3	3	11	5	7	9
		By Heart	6	6	2	12	7	6
		By body movement	4	7			1	
		No response	6	7	4	3	2	
		Other	3	6*	2	1	2	4
	No Responses		3	0	4	2	2	1

* Examples - food pushes the blood (2)
In tiny little pieces

Fig 6.9.2.1. Network showing summary of responses for the nature and function of blood.

		No Response	Purpose & No Mechanism for Circulation		Mechanism & No purpose		Mechanism & purpose		
			Correct	Incorrect	Correct	Incorrect	2 correct	1 correct	None correct
Infants	Pre	3	1	3	1	5	2	10	4
	Post		1	6	1	3	5	7	7
Lower Juniors	Pre	4	2	4	6		3	4	
	Post	2		3	7		3	8	
Upper Juniors	Pre	2		2	5		2	8	4
	Post	2			5		3	11	2

Fig 6.9.2.2. Network showing nature of children's response about the purpose and mechanism of blood and its nature.

6.9.3. Respiration

Question 6 attempted to explore children's knowledge of respiration through exploring whether their responses gave any indication of gaseous exchange. A wide variety of responses was provided to this question and a simple classification schema was adopted which summarised the responses (Table 6.9.3.1).

Essentially the schema represents the researchers' attempts to classify the data into scientific, partially scientific, everyday and other explanations. Using this schema the data obtained from children is shown in Table 6.9.4.2.

Responses indicating an awareness of the process of respirations	***Responses indicating a possible understanding of some aspect of respiration.***	***Everyday responses***	***Unclassifiable/Other***
Air comes down, carbon dioxide comes out.	It goes into your lungs.	Helps us to breathe.	You can smell the air
Turns into carbon dioxide.	It gives air to the blood.	It goes into your tummy.	
	The good bit stays in, the bad bit goes out.	Goes into your mouth and out of your nose	
	We breathe in oxygen.		

Table 6.9.3.1: Schema used for categorising responses to the question 'What happens to the air which we breathe in?'

The general pattern shown by these data is one where little change is apparent. There was some minor improvement in the responses which showed some understanding of aspects of respiration but none of these changes have any statistical significance. What is noticeable is that there is a significant ($p<0.05$) difference in the number of everyday responses provided by the infants and the other two groups prior to the intervention. The intervention sustains this difference and these data reinforce other data that also showed significant differences existing naturally between these two groups.

	Infants		Lower Juniors		Upper Juniors	
	Pre	Post	Pre	Post	Pre	Post
Responses indicating an awareness of the process of respirations	0	0	2	0	1	2
Responses indicating a possible understanding of some aspect of respiration.	2	5	6	10	9	13
Everyday responses	20	20	8	6	8	4
Unclassifiable/Other	2	1	0	1	0	1
No response	5	3	7	6	5	3

Table 6.9.3.2: Data for children's responses on the purpose of breathing

The lack of any improvement in children's understanding raises the question of whether this was due to the failure of the intervention or whether the topic is inherently too difficult for children of this age. This issue will be explored later in greater depth in Chapter 8.

6.9.4. The Process of Digestion

The next question to address children's knowledge of processes performed by the human body was a question which asked them to add to the drawing to show what happened to food and drink inside your body. The responses to an ostensibly simple question were extremely revealing in what they indicate about children's understanding of their own bodies and in turn, those of other animals.

The most noticeable feature was the large number of infant children who failed to show any kind of tube connecting the mouth to stomach/belly. The food was shown intact within the body and simply spreading throughout in an undigested form by a mechanism which was not understood by the children (Fig 6.9.4.1 (a) and Fig 6.9.4.1(b)).

Fig 6.9.4.1 (a) (Age 6)

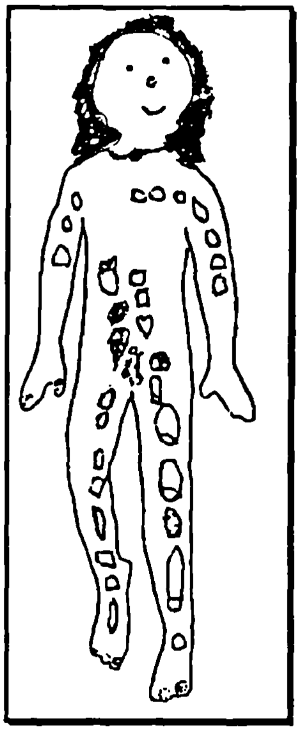

Fig 6.9.4.1 (b) (Age 5)

Two children's responses showing untransformed food.

As with all children's drawings, these responses raise the question whether such drawings represent the limits of children's knowledge or alternatively, the limits of their representational capabilities. However, it should be noted that only younger children produced drawings of this type and that the drawings show a lack of recognition of any physical connection between the mouth and the stomach or inside of the body. Some children who provided such drawings would qualify them with statements such as 'It (the food) goes into the blood. The blood goes everywhere', which would suggest that they recognise that there was a process of at least partial transformation.

What these drawings lend support to is the view that an understanding of the process of digestion requires a comprehension that food can be transformed and broken down into its constituents. Till children understand this idea, the process of digestion will remain a mystery to them.

The next feature to emerge in children's responses was the tendency to draw two tubes from the mouth to the stomach. Fig 6.9.4.2 show a good example of such a response.

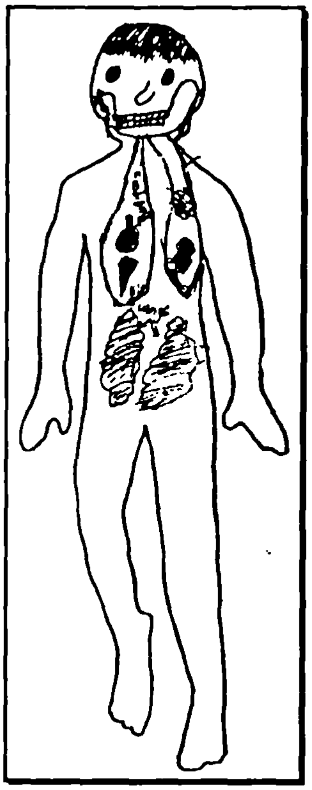

Fig 6.9.4.2: Child's (age 8) drawing to showing two tubes for digestion

In one sense, such drawings are a clear demonstration of children's logic in trying to reconcile their ideas to their observations. Waste products emerge from two different points in the body as liquid and solids. Differentiation clearly takes place and these drawings show a sensible attempt by children to explain their perceptions. It is also worth noting that everyday language i.e., 'it's gone down the wrong way', reinforces the concept of two tubes implying that there is more than one way for food or drink to pass through.

Progression towards a scientific understanding was shown by children whose answer only contained one tube. Fig 6.9.4.3 shows a typical example. The stomach in such drawings was invariably placed in the centre of the abdomen and referred to generally as 'the belly' or 'tummy'.

Such drawings lack any detail or understanding of what happens beyond the stomach. This is in fact the hardest aspect for most children. No infants indicated any aspect of the digestive tract beyond the stomach and only a minority of lower and upper juniors did so and an example is shown in Fig 6.9.4.4. This would indicate possibly that excretion is a relatively poorly understood process by children under 11. An alternative explanation is that eating and excretion are seen as two separate processes by children and not one continuous process.

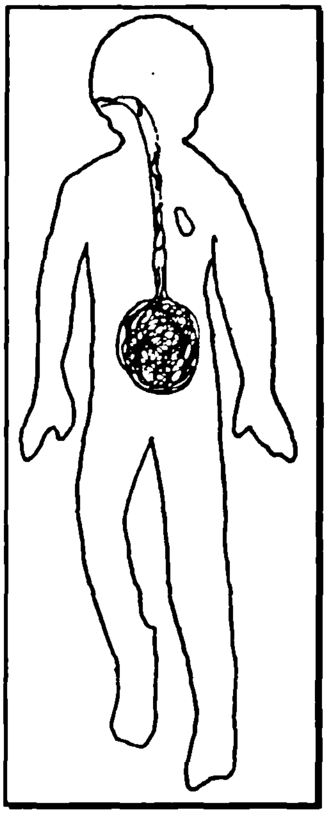

Fig 6.9.4.3 Child's (age 8) drawing showing single tube linking mouth and stomach

The response Fig 6.9.4.4 represents a relatively sophisticated response in that the drawing shows a unitary digestive tract and locates the stomach in an approximately correct position. Only older children produced such drawings and these data, coupled with the evidence of their greater knowledge of internal organs, lend support to the thesis that children's biological knowledge develops between the ages of 5 and 10.

What these data also support is that the child's conception of the body is limited. For many children, it was restricted to that which is directly perceived or sensed. Knowledge that transcends such direct experience is only developed with difficulty over substantial periods of time and it is too easy for teachers to underestimate some of the difficulties children have in this domain.

The data for all these responses were analysed using a network shown in Fig 6.9.4.5. For infant children, the effect of the intervention was to significantly ($p < 0.01$) increase the number of children who showed a tube between mouth and stomach. This represented a positive achievement of the intervention as no understanding of digestion can be achieved until a child begins to assimilate and appreciate the internal connectivity of the parts and organs of the body. No significant changes were found for lower or upper juniors.

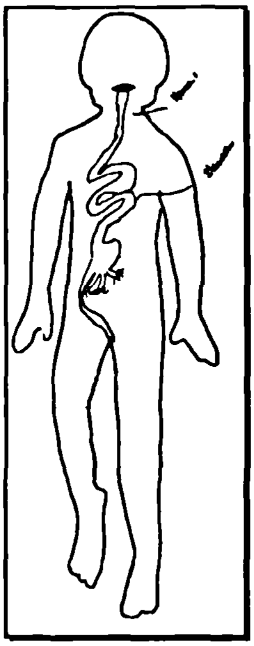

Fig 6.9.4.4 Child's (age 9) response showing good knowledge of digestive tract

A close examination of the data shows that there was a significant difference ($p<0.01$) in the numbers showing a connection between the mouth and the stomach between the infants and lower juniors prior to the elicitation. This suggests that some change in their understanding of children is generated by normal life experiences. The effect of the intervention would appear to be an acceleration of such a change for infants in knowledge and understanding. However, the intervention failed to correct the assumption which was held by a substantial minority of lower juniors and upper juniors that there are two tubes involved in the process of digestion. Whether a proportion of these answers can be explained by a confusion between the oesophagus and the windpipe is an open question as children were not asked to label the parts that they drew on their drawings.

In all cases, only a minority of children indicated any continuation beyond the stomach. The intervention did have the effect of increasing the number of infants showing a continuation from 0 to 8. Again, this effect of the intervention would seem to have been to raise the number of infants providing such a response to the level of the lower and upper juniors prior to the intervention.

For the majority of children, it would appear that, although they may have assimilated aspects of understanding the process of digestion, the mechanism for the disposal of waste was not seen as being one of importance. The overwhelming impression is that children see digestion as a process that occurs solely in the stomach/belly, and that children were probably not aware of the continuation of the alimentary tract.

Representation of Digestive System			Infants n=29 Pre	Infants n=29 Post	Lower Juniors n=23 Pre	Lower Juniors n=23 Post	Upper Juniors n=23 Pre	Upper Juniors n=23 Post
With tubes	2 tubes		0	1	8	6	7	4
	1 tube		6	16	12	13	15	17
		Terminating in Stomach	5	9	13	12	12	12
		Continuing beyond		8	7	7	10	9
		Unclassifiable	1					
No tube/spreads			24	13	3	4	1	2

Fig 6.9.4.5: Network showing nature of children's responses about the process of digestion.

6.10 What weighting or association is given to the processes of life in the child's concept of living thing?

The final question in the elicitation which explored children's understanding of the processes of life was a version of the classic Piagetian research question that asked children to consider the question for a range of objects, 'Is it living, once living or never living?' Despite the extensive history associated with this question, its value in this context was not to explore children's animistic concepts, but as a means for determining whether children were aware of, and used, the processes of life as criteria to answer the question. In particular, the learning goals required that children should be aware that the processes of life are common to themselves and other living things. These processes are movement, growth, respiration, sensitivity, excretion, feeding and reproduction. In addition, all living objects are made of cells.

The question then provides an opportunity to see how many of these criteria were applied to determining whether the object was living. It was thought that the extra category included in the question of 'once living' would offer more choice to pupils and diminish the problem of forcing a dichotomous decision on pupils with the consequence that they may generate abnormal criteria for the decision. Because of the inevitably complex responses to this question, all children were interviewed to obtain their responses to the stimulus items.

The objects/pictures shown to children were three clearly inanimate objects by scientific criteria and the normal criteria adopted by adults - a plastic box, a rock and a spoon; three clearly animate objects - a plant, a mammal and an insect and three objects where the decision is more difficult and depends on a full understanding of scientific criteria. These were a toy car, which was used to explore whether children were using the simple criteria of movement reported by Piaget, and an apple and a seed which from a biological perspective are both living organisms but can easily cause confusion.

The range and diversity of children's response to this question provides a fascinating insight to children's thinking. There is not space to exemplify the range of children's reasoning but three such responses are offered as examples.The first response shows the child's use of a number of criteria. Objects were distinguished by the fact that they can grow, reproduce, are man-made and that they originated from living material.

Object	*Response*	*Reason*
Plastic box	*Never living*	*I don't know*
A small rock	*Once living*	*It was an animal once and it turned into a rock because my dad's friend has got thousands in the house.*
A spoon	*Never living*	*Cos metal is made*
A plant	*Living*	*Because it's growing*
An animal	*Living*	*It's made in an egg*
An insect	*Living*	*It's made just like other animals.*
An apple	*Once living*	*It was alive when it was growing on a tree*
A toy car	*Never living*	*Not sure*
A seed	*Once living*	*They came off another plant*

Table 6.10.1. Child's (Age 9.5) responses to question about living/non-living objects

A different response is shown next (Table 6.10.2). Here the child focuses on a single external feature and repeatedly using this criteria. The simplest explanation of this response would be that the child only recognises visible external features and attempts to use these as a criterion in responding. There is also the possibility that such a response represents the child's attempt to articulate an explanation for a concept that has only been intuitively recognised. Once the child has managed to state an answer for the first time, they continue with the consistent application of the same criterion and do not recognise the need for more thought and reflection about the response.

Object	*Response*	*Reason*
Plastic box	*Living*	*It's round and it's got a hole*
A small rock	*Never living*	*Because it hasn't got any holes.*
A spoon	*Never living*	*Because its only got a hole*
A plant	*Living*	*It's round and big.*
An animal	*Never Living*	*It's round and hasn't got any holes*
An insect	*Never Living*	*They haven't got any holes*
An apple	*Never Living*	*It hasn't got any holes*
A toy car	*Never living*	*Because you can't open the doors*
A seed	*Never Living*	*No holes in them*

Table 6.10.2. Child's (age 6) response to question asking about living/non-living objects

The criteria used by children which emerged from the data were grouped under the headings shown in Table 6.10.3 . This shows the major categories i.e., external structure, internal structure, behaviour, tautological and actions, and examples of reasoning in each category. The category 'Tautological' refers to justifications that simply appealed to the self-evident, that is explanations that deemed the object 'is alive' or 'is dead' and essentially failed to provide any justification for the assertion. The category of 'Actions' refers to all those justifications which were based on what the animal/object was capable of doing or being used for. In addition, there was one extra category for responses which were unclassifiable.

External Structure	*Internal Structure*	*Behaviour*	*Tautological*	*Actions*
No face	Has seeds	Movement	Dead/Alive	Can be eaten
Hard	Comes from an egg	Made to move	Was living	Has a use
Broken	Has a Heart	Grows	Don't live	Has to be made
Bent	Has a Brain	Eats		Can be bought
Got hair	Has lungs	Talks		Play with it
Smooth	Has a Liver	Origin		Perform action on object
Rusty/Dirty/Old	Has Teeth	Dies		
Metal	Has a Stomach	Lives in		
Surface feature	Has a Bones	Drinks		
Breaks	Has Blood	Breathes		
Other		It's like		
Too cold		Gives birth		
It's plastic etc		It sees		
Has Legs/eyes		It sleeps		
Solid				
Has a Nose				
Has Ears				
Has Mouth				

Table 6.10.3: The five categories used for classifying children's responses with all response types listed in each.

The results obtained are summarised using this classification in Table 6.10.4 beneath. The predominant feature that emerges from the data was the use by children of two broad groups of criteria for their response - that of behaviour, where the major criteria is whether the object is capable of growth and/or movement, and the external structure particularly by infant children. .

These figures clearly shows that the importance of external structure diminishes and that the pupils attention focus more specifically on the behaviour of the organism as they get older. The predominant criterion used is that of movement which can be seen from the

Reason	**Infants**		**Lower Juniors**		**Upper Juniors**	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
External Structure	35%	15%	16%	11%	16%	10%
Internal Structure	0%	8%	0%	2%	2%	10%
Behaviour	38%	51%	59%	70%	62%	67%
Tautological	5%	1%	2%	1%	0%	3%
Actions	18%	20%	9%	9%	13%	4%
Unclassifiable	1%	2%	6%	1%	1%	3%
No Criteria	2%	3%	8%	6%	6%	4%

Table 6.10.4: Table showing percentages of children's responses in each category.

number of responses that mention *specific* processes of life (Table 6.10.5). All of these categories are a subset of the major groupings of 'behaviour' defined in Table 6.10.3 and the data are given to show how often such processes were used as criteria.

Process of Life	**Infants (n=261)**[1]		**Lower Juniors (n=207)**		**Upper Juniors (n=207)**	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Movement	35	70	66	74	57	74
Growth	9	25	39	61	41	61
Reproduction	0	0	1	7	2	7
Digestion	6	6	11	15	13	15
Respiration	0	3	10	14	9	14
Sensitivity	0	0	0	0	0	0
Excretion	0	0	0	0	0	0

Table 6.10.5: Numbers of responses by children using the criteria of specific processes of life.

1. The sample size here is the total of all possible responses that could have been made.

An examination of the data shows that two changes for the infants pre and post-intervention were significant at the 1% level. These were the diminishment in the response mentioning external structure and the increase in the number of responses falling in the behavioural category. An examination of responses that were specific to the processes of life showed that part of the contribution to the significance was the increase in the number of responses using movement as a criteria ($p<0.05$) and growth ($p<0.05$). Significances were not calculated when responses in any one category were less than 10.

It should be noted that there was a significant difference between infants and lower juniors prior to the elicitation in the number of the responses they give mentioning external structure (Table 6.10.4) - infants giving many more. This would suggest that the change that occurred as a result of the intervention was simply an acceleration of an event which happens naturally.

The two other significant changes in the data were the increase in the number of responses based on the behaviour of the organism ($p<0.01$) by lower juniors, and the decrease in the number of responses based on actions by upper juniors ($p<0.01$). Table 6.10.5 shows that the former change is explained by the larger number of responses given by lower juniors which mention the process of growth as a criterion of judgement and the latter change simply by a reduction in the number of upper juniors who mention actions (Table 6.10.4).

The results shown here give some support to the work of Piaget and others which indicate that the predominant criterion deployed by children was that of movement. However, what they show in addition, is that these children used a variety of criteria, particularly those based on external structure. The data also show some evidence that an increasing number of children use scientific criteria as a basis for judgement. These data then would support the work of Lucas et al (1979) who found similar results in their work. Hence like Lucas, it is argued that such work has ignored the 'richness of children's responses' to this complex question and attempted to adjust the data to fixed categories which our data can not support.

A further analysis of the development across the age range was obtained from examining the number of statements used by children to decide on whether an object was living, once living or never living; the range of categories of criteria that they use and the number of statements which they get scientifically correct. The data are shown in table 6.10.6.

	Infants		Lower Juniors		Upper Juniors	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Total No of criteria used.	279	291	235	272	214	296
Total No of Categories of Criteria used.	81	84	58	54	57	51
No of objects correctly identified as alive	121	150	135	146	144	149

Table 6.10.6: Data obtained on total No of criteria used, No of Categories and No of objects identified as alive for the whole sample.

An examination of the data by inspecting the averages for the groups (Fig 6.10.2) shows that, for each child, the reduction in the number of categories used was accompanied by an increase in the number of criteria and an improvement in making the correct scientific judgement of whether an object was living or not.

What is clearly missing from children's understanding at any level was any recognition of excretion or sensitivity i.e. response to stimuli as being a criteria for determining whether an object was living or dead. These were not processes generally perceived by children or projected to other organisms. Either, because the processes are difficult to observe easily, which hardly seems possible, or more likely, that such processes have not been drawn to the attention of children by their teachers and parents.

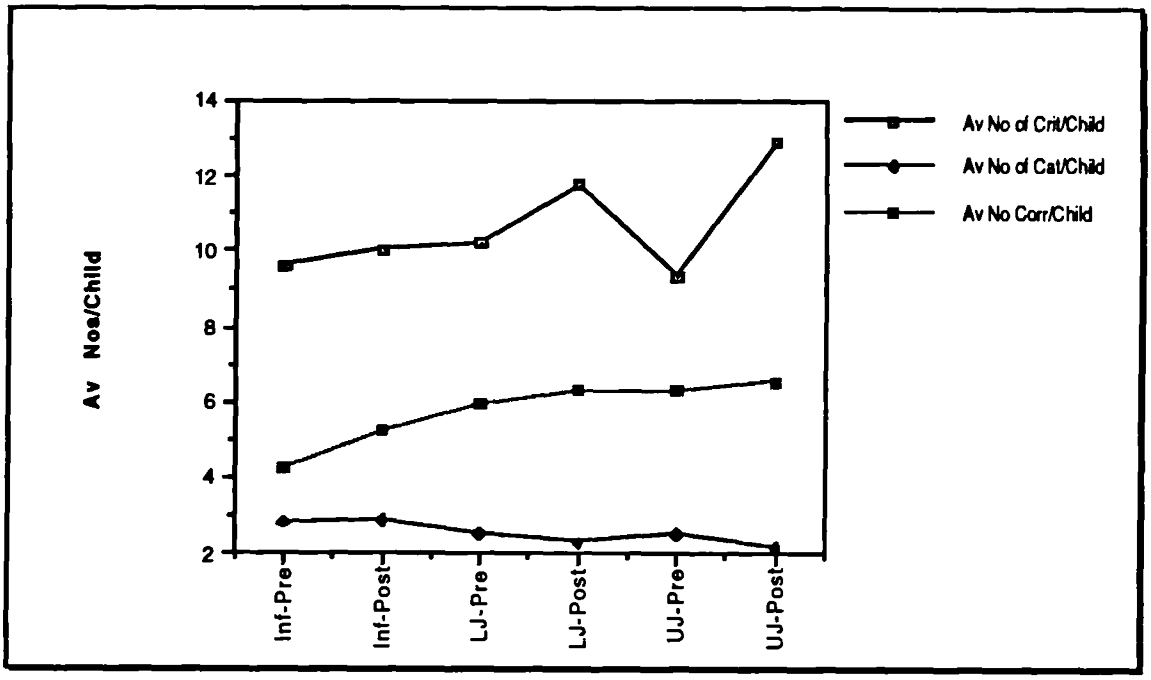

Fig 6.10.2: Chart showing variation in Average No of criteria; average No of correct decisions as to whether the object was living, once living or never living and average No of categories used.

6.11. What is the child's knowledge of plants and their parts?

Only one question was used to explore this aspect of their knowledge where children were asked to label a drawing in both the pre- and post-elicitation. The limited exploration of this aspect of their knowledge was in part a reflection of the apparent emphasis within the National Curriculum. In the then version (DES, 1989), these stipulated that children at Level 1 of understanding should 'be able to name the external parts of the human body/plants, for example, *arm, leg/flower, stem*' and at level 4 should 'be able to name the major organs and organ systems in flowering plants and mammals'. Hence the intention behind the question used was simply to examine whether children were at all capable of meeting the requirements of level 1.

Traditionally, science education has given little emphasis to this domain of knowledge, a fact which has led one commentator to lament 'Where have all the flowers gone?'(Honey, 1987). Hence it was decided to simply use a diagram of a flower and ask children to name the parts indicated with a label. The four parts were the flower (or petals), the leaves, stem and roots. Answers that used the correct name or an appropriate terminology i.e. petals for flower, or stalk for stem were coded as being acceptable. Data obtained are shown in Table 6.11.1.

The data show that apart from infants, nearly all children were capable of labelling the main parts of a flower. None of the changes observed in the intervention was significant. The simple explanation is that since most children were successful prior to the intervention this was not a area of conceptual understanding that could be significantly improved, although the table does show that all the changes bar one represented an improvement in the number of children who were capable of giving a sensible or correct answer.

		Infants		Lower Juniors		Upper Juniors	
		Pre %	*Post* %	*Pre* %	*Post* %	*Pre* %	*Post* %
Flower	*Right/ sensible*	90	77	87	91	96	87
	Incorrect	10	23	13	9	4	13
Leaves	*Right/ sensible*	83	97	100	100	87	96
	Incorrect	17	3	0	0	13	4
Stem	*Right/ sensible*	40	60	91	91	83	87
	Incorrect	60	40	9	9	17	13
Roots	*Right/ sensible*	33	43	83	96	91	91
	Incorrect	67	57	17	4	7	9

Table 6.11.1: Data for responses to question asking children to label parts of a flower.

Since the time that the research was undertaken, the National Curriculum Order has been changed to specify that it is the organs of the plant that children should be able to name. To some extent, this question shows children's capacity to name the parts but a more detailed question would have been required to explore the present needs of the National Curriculum.

7. *The Earth in Space - Children's Understanding of Astronomy and its Development*

7.1 Introduction.

This chapter reports the research carried out into children's understanding of 'The Earth in Space' by the SPACE project and reported in Osborne et al (1994). The approach and methodology were similar to that carried out for the domains of 'light', 'electricity' and 'processes of life'. A description of the general approach using a pilot and exploration phase, followed by elicitation of children's thinking, an intervention and post-elicitation can be found in section 3.3. The format of this chapter follows that of Ch 4, 5 and 6. However, for the sake of brevity, and since the style of working has been clearly demonstrated, the research review which helped to form an interpretive framework for the data, and to guide the formulation of interview protocols and tasks can be found in Appendix 3. Brief details are provided of aspects of the elicitation and intervention that are exclusive to this domain. However, the majority of the chapter is devoted to reporting the data and findings of the research work.

7.2. The Research Programme

Classroom work on the topic of 'the Earth in Space' took place over a relatively long period in the school year which can be summarised as follows.

Pilot Exploration	Sept 90
Pre-Intervention Data Collection	Oct 90
Intervention	Nov 90
Post-Intervention Data Collection	Dec 90 -Jan 91

The pilot exploration phase was based on interviews with a small number of children (15) and followed the same procedures as outlined in section 6.3.

The classroom elicitation techniques were refined by the pilot process and the experience provided an opportunity for teachers and researchers to develop familiarity with the material and with each other. Data on children's ideas were then collected from children in classrooms using the selected activities. These questions and activities are shown in Appendix 7a. Again all the data from infant children were collected by interview and drawings as these children found it very difficult to provide written answers to questions.

7.3 Defining Learning Goals for 'Earth in Space'

As with the previous domains it was necessary to define what a preferred understanding of astronomy for a child would be. By the time, this research was conducted, the National Curriculum Order was well established. Whilst the learning objectives, defined as attainment targets, are open to question, they represented at the time, the standard objectives that many teachers would be using for their teaching. Therefore these statements (Table 7.3.1) and the associated programme of study (Table 7.3.2) were adopted as guidelines of what it might be reasonable for a child to be expected to know. This does not imply acceptance that these statements are reasonable expectations . One of the subsidiary aims of this research is to examine to what extent, as a consequence of the experiences that were provided by this research programme, such ideas do develop in children and at what ages.

Level	Old Attainment Target[1]	New Attainment Target
1	Pupils should: • be able to describe through talking, or other appropriate means, the seasonal changes that occur in the weather and other living things. • know the danger of looking directly at the Sun. • be able to describe, in relation to their home or school, the apparent daily motion of the Sun across the sky.	Pupils should: • be able to describe the apparent motion of the Sun across the sky.
2	• be able to explain why night occurs. • know that day length changes throughout the year. • know that we live on a large, spherical, self-contained planet, called Earth. • know that the Earth, Moon and Sun are separate bodies.	• know that the Earth, Moon and Sun are separate spherical bodies
3	• know that the inclination of the Sun in the sky changes during the year. • be able to measure time with a sundial.	• know that the appearance of the Moon and the altitude of the Sun change in a regular and predictable manner
4	• know that the phases of the Moon change in a regular and predictable manner. • know that the Solar System is made up of the Sun and planets, and have an idea of its scale. • understand that the Sun is a star.	• be able to explain day and night, day length and year length in terms of the movement of the Earth around the Sun
5	• be able to relate a simple model of the solar system to day/night and year length, changes of day length, seasonal changes and changes in the inclination of the Sun. • be able to observe and record the shape and surface shading of the phases of the Moon over a period of time.	• be able to describe the motion of the planets in the solar system

Table 7.3.1: Attainment Target 1-5 of the English & Welsh National Curriculum (DES, 1989) and (DES, 1991)[1] for the Earth in Space component

1 Since the publication of this Order, a revised publication has been produced by the Department for Education in 1991. The work reported here was based on the original Order. The summary and conclusions of this work are based on the new order (DES, 1991)

The programme of study was as follows.

Key Stage 1	Children should observe closely their local natural environment to detect seasonal changes, including day-length, weather and changes in plants and animals, and relate these changes to the passage of time. They should observe, over a period of time, the length of the day, the position of the Sun, and where possible the Moon, in the sky. They should investigate the use of a sundial as a means of observing the passage of time[1].
Key Stage 2	Children should be given the opportunity to investigate changes in the night sky, in particular the position of the Moon, through direct observation and by using secondary sources. Children should use a simple model of the solar system to attempt explanations of day and night, year length and changes in the aspect of the Moon and the elevation of the Sun. They should be introduced to the principle of the sundial as a means of noting the passage of time. They should learn about the position and motion of the Earth, Moon and Sun relative to each other[2].

Table 7.3.2: Programmes of Study for the English & Welsh National Curriculum in Science at Key Stage 1 & 2.

These ideas also provide a framework for examining children's ideas allowing three questions to be addressed.

a) How different were the conceptions held by many children from such a framework and how disparate were their ideas?

b) What development was observable in children's ideas across the age range?

c) What potential did the planned intervention have for the development of children's ideas towards the scientist's view?

This list was also used as a reference point for the development of the intervention. Given such a framework of objectives, the intervention task was to develop activities which would assist the formation of a fuller understanding of this domain by children.

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1 In the 1991 order, this last sentence has been omitted from the programme of study for KS1 and added to the KS2 programme of study. There are other minor changes to the wording.

2 The only significant difference between this version of the order (1989) and the 1991 version is the addition of the sentence 'They should be introduced to the order and general movements of the planets around the Sun'.

The activities were devised using simple materials familiar to children. Their primary role was to provide a focus for discussion of children's thinking and to challenge their existing ideas.

7.4 The Intervention

The general rationale that underpinned the design of the intervention was identical to that which has been outlined in section 3.3.3

The selection and design of the activities for the intervention was influenced by three factors:

(a) A preliminary analysis of the data.

(b) A set of ideas defined by thc 'scientific' understanding (Section 7.3) which would assist a child in developing an understanding of the scientific world view.

(c) The teacher's contributions and ideas.

The elicitation gave a broad picture of the level of children's knowledge and understanding in this domain. Essentially, this had shown that there was a lack of simple observational knowledge about the daily movement of the Sun, a weakness in infant children's knowledge of time, a limited familiarity with distance and scale and a mixture of models about the movement of the Earth and Sun. Unlike some other aspects of science e.g. electricity and light, such knowledge cannot be shown or developed through empirical investigations which are a feature of much primary science education. Hence, the intervention used a range of broad strategies which were available for teachers to use whenever they judged appropriate. These can be described as a) sorting activities, b) discussion activities, c) modelling/making activities, d) using secondary sources and e) simple observations and drawings. Full details of the intervention strategies suggested to teachers can be found in Appendix 7b.

Sorting Activities
These activities require the active processing of information by children. Typically they would be provided with a number of cards. Each card would have the name of a planet written on it and the children were asked to sort the planets into an order such as 'largest' to 'smallest' or 'nearest to the Sun' to 'furthest from the Sun'. Teachers were also asked to provide children with ample opportunity to explore their own approaches to the categorisation of the planets such as 'hot planets' and 'cold planets', or big and small planets.

Another use of sorting was to ask children to group sets of statements about the seasons e.g. 'daffodils are out', 'snow falls' into groups to help to establish clear associations between phenomena and the seasons. An additional exercise was to use data published in the newspapers of temperatures around the World to group cities into 'cold' places and 'warm' places to see if children could see any pattern between their geographical location and the temperature.

Discussion Activities

Many of the sorting activities discussed previously were undertaken by groups and hence required discussion and communication between peers which encouraged both articulation of their own thinking and the exchange of ideas. Wherever possible, activities were used that encouraged the use of this technique.

For instance, children were asked to discuss in groups sets of statements on cards about physical phenomena such as 'The Sun goes to bed at night', 'The Sun does not move, the Earth spins' and decide whether they firstly individually agreed or disagreed with such statements and then come to a group consensus about each statement which was later discussed with their teacher. Another suggested method of using this technique was to use historical ideas about the Earth and its movements and ask children to find evidence which supported or contradicted such statements. Possible starting points were statements of the form 'Some people think the Earth is flat and some think it is spherical' or 'Some people think the Earth goes around the Sun and others think the Sun goes around the Earth'.

Modelling/Making Activities

Models provide a tangible and concrete experience of objects which are not readily open to inspection such as the Solar System itself. Thus they are an essential aid to helping children develop an understanding of how the bodies of the Solar System might move, and how these movements would account for the phenomena that we observe. Therefore one of the activities suggested to teachers used pairs of children to represent the Sun and the Earth and asked them to act out their daily and annual movements. Such an activity can also be done for the movements of the Earth and the Moon.

Making timelines was suggested as an activity which enabled a concrete representation of time to be made. This is a useful activity for younger children to help establish the idea of 24 hours in a day, 7 days in a week and can be extended for older children into a timeline for a year of their lives. Additionally, is motivational if it records their own it personal experiences. The thinking was that such a simple concrete characterisation of time would help the assimilation of the arbitrary symbolic representation commonly used in our culture.

Another suggested activity was intended to provide children with an extended experience of a range of shapes and enhance their vocabulary for describing them. Children were asked to select a shape from a box and then, keeping it hidden, describe it to another child who had to guess the singular name for this shape.

The final model making activity suggested was to use torches and shadows to explore how shadow length is related to the position of the source and the size of the object. It was suggested that children be encouraged to relate this to the shadows formed by the Sun providing opportunities, whenever possible, to investigate the length and other features of such shadows.

Using Secondary Sources

Possibly more than any other domain of science, astronomical knowledge is elaborated or provided by secondary sources, typically books and posters. Teachers were therefore encouraged to assemble a collection of such resources which children could access for information. To aid children to use and record information collected in this manner, it was suggested that they be asked to keep scrapbooks or logbooks in which they could stick pictures cut out from magazines and other notes and information. Scrapbooks could either be collected on an individual, group or class basis and could be valuable as a stimulus for discussion with children.

For older children, there are strong arguments for activities which require directed reading of texts which encourage active and reflective reading. Such pieces and their associated techniques are commonly known as DARTS (Directed Activities Related to Text) and two of these were provided for teachers as exemplars of the kind of material that could be used to assist learning from secondary sources.

Simple Observation and Drawing

Working in an urban environment, only limited observations of the night sky can be undertaken. Nevertheless, it was considered worthwhile encouraging teachers to ask children to undertake observations of the Moon on a monthly basis, particularly if these were undertaken as a class task where each child had responsibility for one night. This would help to establish an idea of the phases of the Moon and the sequence of their changes.

Drawing activities considered were the production of simple posters and mobiles of the Solar System which are an effective means of recording a large amount of data. A slightly more demanding task was to ask children to work as a group and produce a drawing of an asymmetrical object e.g. a teapot, firstly from their perspective and then from one of the other group member's perspective. Such a task requires the child to transcend their egocentricity and imagine how another sees the object. This mental process is essential to understanding the phases of the Moon and the apparent daily movement of the Sun across the sky.

7.5. Children's Thinking and The Effects of the Intervention

7.5.1. Introduction

This section provides a full analysis of the data gathered pre- and post-intervention. The data were gathered using a mixture of written questions and interviews which are provided in Appendix 7a.

Classes of children were asked to write their answers to all the questions in sections A-C which included any questions that required drawings e.g. a drawing of what the Earth, Sun and Moon would look like from the window of a spaceship. Responses to all the questions in section D were obtained by individual interviews with children. The interviews made use of a set of shapes consisting of 2 large spherical balls, 2 small spherical balls, 2 large discs, 2 small discs and 2 rectangular shapes which were shown to children. Each child was then asked to select from these shapes and use them in answering the questions that followed. The child's responses were then noted by the interviewer.

Data were gathered in two phases, an elicitation phase prior to the intervention and a further follow-up phase after the intervention. The intervention work was generally undertaken over a 'half-term' period and consequently these two phases were generally separated by a period of 6-8 weeks. The questions used in both phases were identical The data were gathered by the full-time project officer, two part-time researchers and two teachers.

During the pilot phase, through a process of collaborative discussion, analysis of children's responses and consideration of the learning goals, information that answered the following questions was identified as being central to establishing a picture of the growth of children's knowledge in this domain.

7.5.2. Questions considered by the research

1. What understanding of time do children have?

An understanding of the arbitrary divisions that constitute our notions of time was considered to be an a priori requirement for any discussion of astronomical events such as day, night, phases of the moon and seasons. Hence a simple question was used to ascertain whether children had grasped the normal social construction of time, that is how long a day, month and year were (question 1, section A).

2. What do children know about the movement of the Sun through the year?

Questions here aimed to explore firstly to what extent children were aware of the difference in the altitude of the midday sun between winter and summer (Question 2, section B) and related seasonal effects (Question 1, section B). Another question explored children's abilities to use a model to show the relative motion of the Sun and Earth during the course of one year (Question 1(c), section D). A final question explored this aspect further by asking children to use the model to explain the variation in day length and temperature between summer and winter (Question 2, section D) .

3. What explanations do children give for the phenomena of day and night?

Children's explanations of day and night have been the focus of many studies. This study used a range of questions to explore what children thought happened (Question 3(a), section A, Question 1 (b), section D) and why it happened (Question 3(b), section A). Questions were based on written/spoken explanations and asked children to use shapes, selected from those provided, to demonstrate the relative movements of the Sun and Earth.

4. What do children know about the daily movement of the sun and related phenomena?

These ideas were explored through the use of two questions using drawings where children were asked to make additions in order to show the diurnal movement of the Sun and its effect on shadows (Question 2, section A and question 3, section B). A further item. was used to see if children could use any understanding they had of the Sun's daily movement to explain how a sundial works (Question 4, section B).

5. What concept of the Earth do children have?

The problem for children is to make the transition between the readily observable concept of a 'flat Earth' with a clearly delineated notion of 'down' at right angles to the two horizontal planes of the ground and the sky, and the scientific concept where 'down' is towards the centre of the Earth. Three questions using a mixture of spoken/written explanations and drawings to investigate what kind of concept of the Earth was held by these children (Questions 1 & 2, section C and question 1(a), section D).

6. What is children's knowledge of distance?

One of the elements required to understand astronomy is a conception of distances. A sense of awe and the insignificance of human lifetimes and scales can only really develop from an appreciation of the enormity and grandness of the Solar System/Universe. Hence one item asked children to provide an estimate of terrestrial and astronomical distances to provide an insight into what extent this sense of distance had been grasped and appreciated by children (question 4, section D).

7. What knowledge of astronomical bodies do children have?
This aspect of the research explored what knowledge children had of the phases of the moon, the concept of a planet and star, and of their relative sizes. Knowledge of the phases of the Moon was explored by asking children to indicate which phases they had observed by marking a set of shapes (Question 5, section B). The second part of this question investigated whether they had any concept of the correct sequence. Their ideas about the shape and size of the Earth, Sun and Moon were explored by asking children to draw these objects as seen from a spaceship to see if they had any concept of their relative sizes (Question 3, section C). Question 4(a), section C was a simple test of whether children were able to distinguish stars from other astronomical bodies whilst question 3, section D asked children to describe what a star was. Another item tested whether children could distinguish planets from other astronomical bodies(Question 4(b), section C), and finally, a sorting activity testing if children had any conception of their comparative sizes of a range of astronomical objects was used question 5, section D).

7.5.4. Sample

The data presented here are those obtained from children who were present on all three occasions i.e. the elicitation, the intervention and the second elicitation. Full sets of data were obtained from 106 children in total. This consisted of 39 upper juniors in year 5 & 6 of their education, 31 lower juniors, in year 3 & 4 of their education and 36 infants in year 1 & 2 of their education.

7.5.5 Data Analysis

The methodology used in analysis of the data was firstly a simple categorisation of the answers and a frequency count. Categorisations were based on an empirical approach to the data from the responses provided by children. As had been done with other domains, data pre- and post-elicitation were then compared using cross-tabulations and chi-square tests to see if significant changes had occurred. In this case, data analysis was extended by investigating the data sets for significant correlations to see the extent to which children were consistent in their responses between questions. At a theoretical level, this information is important as some authors have argued that children are operating with a consistent theoretical structure, albeit a non-scientific one whereas others have argued that children's knowledge consists of a set of unrelated phenomenological primitives e.g. notions of 'support' and 'effort'. The application of the latter principles is dependent on the surface features of a problem and hence results in contextual inconsistency.

For those data where there were two or more aspects to the response i.e. in children's explanations of day and night (Section D, Q1), the data were analysed using systemic networks. The data and a discussion of the findings are reported under the heading of each question considered.

7.6. What understanding of time do children have?

This aspect of children's knowledge was explored because a child who does not have a concept or 'feel' for what is commonly understood by a day, week or year was thought unlikely to be able to give anything more than what Piaget termed an 'artificialistic' explanation of such phenomena, i.e. night happens because God makes it happen which is in essence, the *deus ex machina* view. After some discussion of the best method of exploring such knowledge and the results of the pilot, it was decided to use a set of simple questions which asked how long a day, week and year were.

Children were asked 'How long is a day?' and provided three categories of response, 12 hours, 24 hours or no response/don't know. Table 7.6.1 shows the data obtained for the numbers children gave and Table 7.6.2 shows the data for the unit used to qualify the number. The main features of note were the highly significant ($p<0.01$) distinction between infants and lower and upper juniors, both before and after the intervention. The latter two groups were much better at providing a response that indicated that they had grasped the commonly accepted understanding of day length prior to the intervention.

	Inf-Pre % (n=36)	*Inf-Post* % (n=36)	*LJ-Pre* % (n=31)	*LJ-Post* % (n=31)	*UJ-Pre* % (n=39)	*UJ-Post* % (n=39)
12 hours	11.0	8.0	6.0	0.0	3.0	3.0
24 hours	14.0	25.0	65.0	90.0	92.0	92.0
No Response	75.0	67.0	29.0	10.0	5.0	5.0

Table 7.6.1: Percentage of children indicating each type of response for the different age-groups to the question 'How long is a day?'

The main intervention activities suggested to develop children's understanding were based on work on timelines and sundials (Appendix 7b). Although neither the improvement in the knowledge of the infant or lower juniors was significant, the overall result was that the distinction between lower juniors and infants became even more substantial (and significant).

Table 7.6.2 shows the data obtained for the units of time children gave in their responses. Not surprisingly, the pattern of changes between infants, lower juniors and upper juniors for the figures shown in table 7.6.1 and 7.6.2 and their significances were more or less identical. Essentially this was because of the large number of infant children who gave no response to the item and hence provided neither a figure nor a unit. However, the changes for each group between pre- and post-elicitation do differ.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Units given	36	42	81	81	87	92
Units not given	64	58	19	19	13	8

Table 7.6.2: Data showing percentage of children who gave units when asked 'How long is a day?'

Clearly only a minority of infants appeared to be aware of the length of a day and the transition between the infants and the other groups is shown more dramatically by Fig 7.6.1. This chart also shows that the intervention has had an effect in improving the number of children who were able to give the correct response in both infants and lower junior children. Upper juniors would appear to have reached a plateau of understanding with only a very small minority who did not appear to be aware of the correct figure.

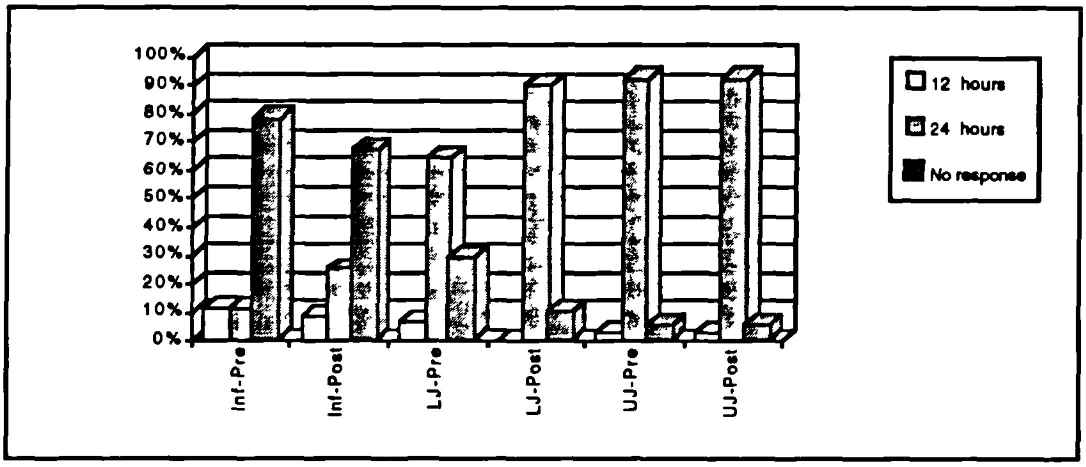

Fig 7.6.1. Chart of data showing the percentage of each age group giving each type of response to the question 'How long is a day?'

Fig 7.6.2, 7.6.3 & 7.6.4 show the percentage of children who were able to give a correct answer respectively for the length of a day, the length of a month and the length of a year. In coding the responses to the question about the length of a month, 4 weeks, and 28-31 days were both considered acceptable responses.

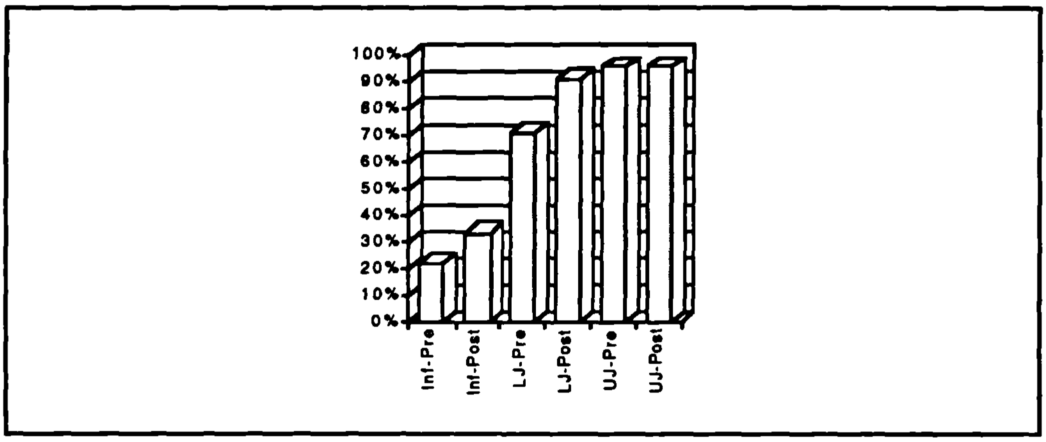

Fig 7.6.2. Percentage of children in each group who gave a correct answer to the question 'How long is a day?

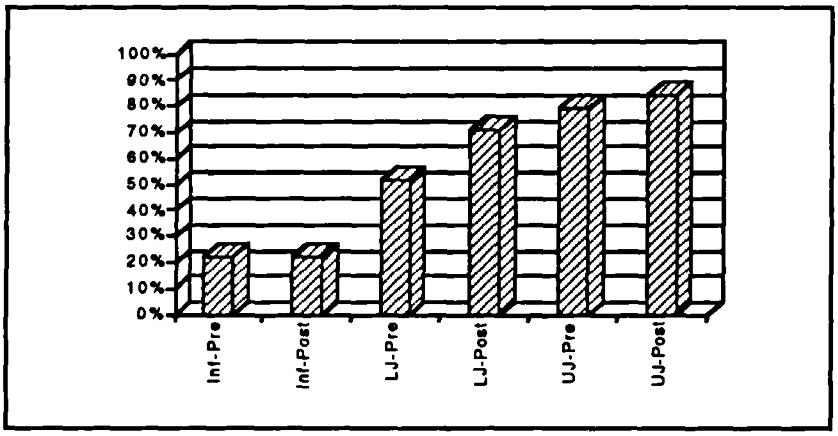

Fig 7.6.3: Percentage of children who gave a correct response to the question 'How long is a month?'

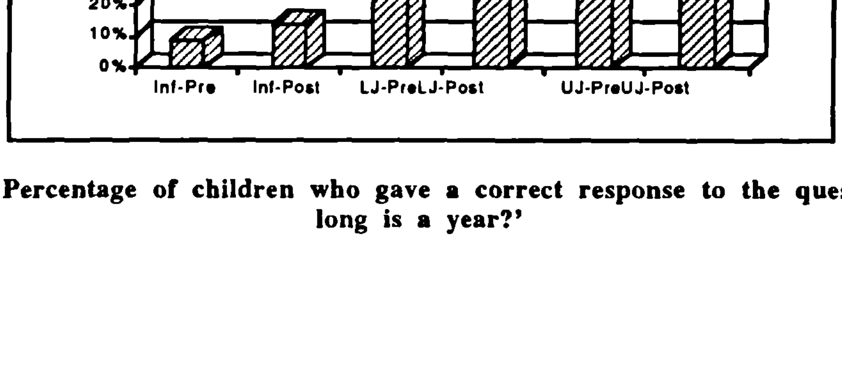

Fig 7.6.4: Percentage of children who gave a correct response to the question 'How long is a year?'

The figures for the units given in the children's responses e.g. day, month etc, to the question asking how long is a month were collected, irrespective of whether the numerical value was correct, and are shown in Table 7.6.3.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Day	19	25	29	23	21	51
Week	11	14	29	55	49	38
Both	19	22	6	3	5	3
No Unit	50	39	35	19	26	8

Table 7.6.3: Data showing percentage of children of each age group pre- and post-intervention who gave a unit when answering the question 'How long is a month?' (percentages have been rounded)

An analysis of these data for their responses show that, although the intervention led to an improvement in children's performance for all groups, none of the changes for the individual age groups was significant. Comparing the groupings before the intervention though, there was a significant difference ($p<0.05$) between the infants and lower juniors in the number providing the correct response which increased as a consequence of the intervention ($p<0.01$). The significant difference between lower juniors and upper juniors prior to the intervention ($p<0.05$) was not significant after the intervention. This suggests that the largest change in knowledge and understanding as a consequence of the intervention was for the lower junior group. A tentative explanation of this change might be that whilst it was fairly hard for young children to assimilate the concept of a day, let alone a month, older children were building on the concept of a day which the evidence in Tables 7.6.1 and 7.6.2 shows was already well formed.

The data for children's responses to the question 'How long is a year?' show a similar trend (Fig 7.6.4) to the data from the previous questions. Table 7.6.4 shows the percentage of children who gave a unit in their answers.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Unit	36	44	35	61	82	77

Table 7.6.4: Percentage of children who gave a unit in their response to the question 'How long is a year?'

Whilst it would be erroneous to treat the data shown in Figs 7.6.2 - 7.6.4 as representing a developmental curve because they show the results for three different sets of children taken at two different times, they do depict a clear trend in children's understanding. The most obvious feature was the improvement in the number of children from pre- to post-elicitation for all age groups, and from age group to age group, who gave a correct or an approximately correct number for the length of a year. This was accompanied by a similar trend, not quite as marked, in the number who provided a unit. Both infants and lower juniors showed an improvement from pre- to post-elicitation but upper juniors effectively seemed to have reached a plateau. Both these changes are accompanied by a marked decline in the number giving no response.

A closer examination of the changes in their understanding of the concept of a year shows that the intervention led to a significant improvement in the understanding of the lower juniors ($p<0.05$). However significant differences in understanding existed between the infants and lower juniors ($p<0.01$) and between lower juniors and upper juniors ($p<0.01$) prior to the intervention. Hence the major effect of the intervention would seem to have been to raise the understanding of the lower junior group.

The low facility values achieved by infants in their responses to these questions would suggest that they were not in a position to assimilate the concept of a year and the data show that there was little improvement in their understanding. On the other hand, the data also suggest that there is no need for this topic to be covered beyond the lower junior age group as the evidence shows the concepts are well-assimilated by the overwhelming majority.

It is also interesting to examine what correlations, if any, exist between those children who knew the correct answers to one question and another - the hypothesis being that those who knew about year length should be able to correctly predict the length of a day and/or a month as these are effectively sub-units of a year. Correlations were investigated to explore the extent to which those who are successful in predicting day length are also successful in predicting month or year length. The data showing the percentages who gave the correct response to each question are shown in Figs 7.6.5a, 7.6.5b & 7.6.5c (in brackets). In addition, the figures (joined with square brackets) show the percentage who were successful on two items. Figures to the far left and right show the percentage who were successful on all three items.

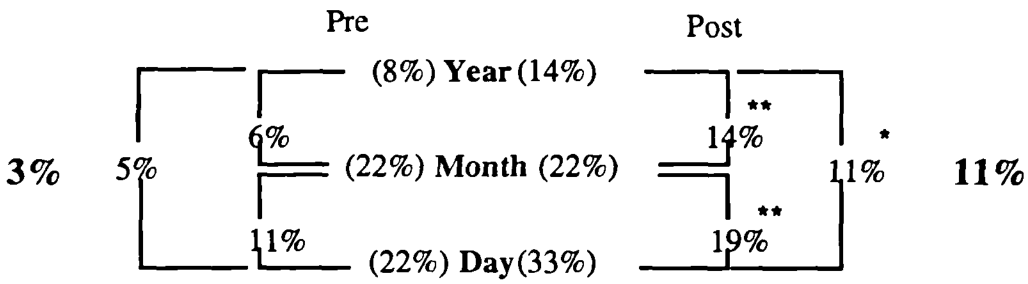

Fig 7.6.5a: Table showing data for infant responses and the percentages successful on one or more responses. (, * - see text beneath).**

There are several coefficients which can be calculated to measure the correlation between children's responses to these separate items of data. A simple cross-tabulation and chi-squared test gives a measure of the association between the two items and its significance. Another indicator, called the index of agreement (r_g)[1] and known as the G index (Guilford, J.P & Fruchter, B, 1981), measures the extent to which children who succeed/fail on one item succeed/fail on another. The latter coefficient is useful in providing evidence of the extent to which a child's responses to two aspects are positively interrelated. If responses require the application of the same schematic knowledge, it is a reasonable hypothesis that lack of such schematic knowledge would lead to failure on both items. The calculation of a significance value using chi-squared for the relationship gives some indication of the extent to which each distribution is non-random and that there may be something underpinning the relationship.

When both items fail to elicit any appropriate schema, or alternatively, when the knowledge is so well understood that the responses to both items are almost always correct, a high index of agreement will be obtained. However, where such a distribution occurs, the chi-square statistic will show less significance. The case where the index of agreement is high and the chi-square statistic shows significance is more definitive evidence that performance on these items are critically interdependent. Such cases are shown in these diagrams with an asterisk (* - $p<0.05$) and a double asterisk (** - $p<0.01$).

For the infant groups, all the indexes of agreement were greater than + 0.5 on a scale of total negative correlation (-1) to total positive correlation (+1). All of these high indexes prior to the intervention are explained by the large number of children who failed to answer any item successfully. After the intervention, the indexes of agreement were all in excess of +0.5 but this time the chi-square statistic showed that there was a significant association between their responses.

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1 The index of agreement is simply a coefficient which gives the difference between the fraction of those cases who agree on both items and those who disagree.

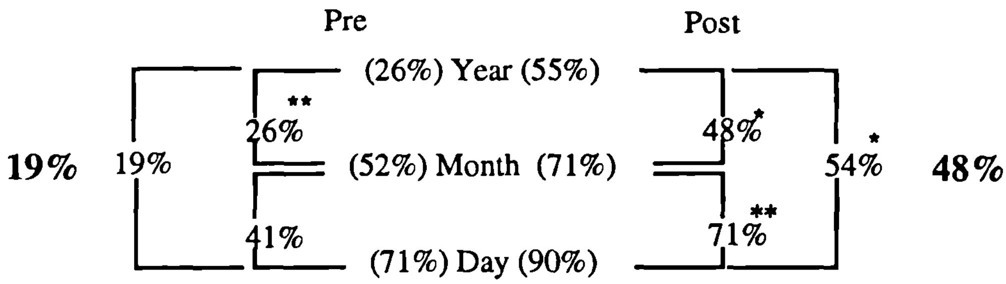

Fig 7.6.5b: Table showing data for lower junior responses and the percentages successful on one or more responses. (, * - see text above).**

The data for the lower juniors showed a similar pattern to that for the infants. Larger numbers of children were successful in their responses to these items and the correlations were more significant after the intervention than before, demonstrating some evidence that an appropriate schema had been developed.

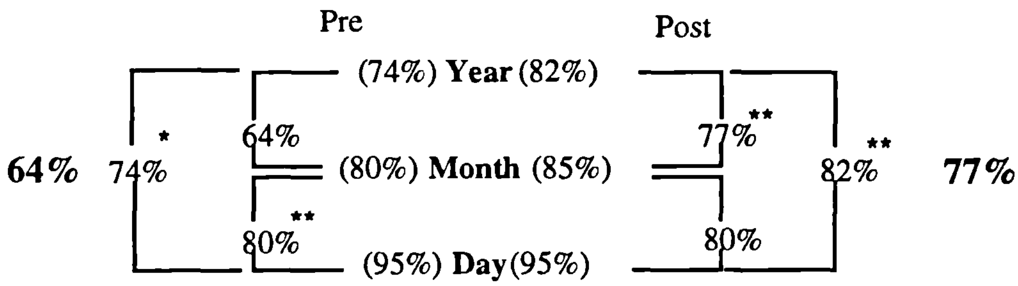

Fig 7.6.5c: Table showing data for upper junior responses and the percentages successful on one or more responses. (, * - see text above).**

The data for the upper juniors show a much higher level of success with responses to these items. In this case, the indices of agreement between all these items were 0.48 or greater. The high level of agreement was explained by the numbers of children who had no difficulty in replying to these items correctly so that after the intervention the relationship between responses for day length and month length has no significant association. However the data do show that there were significant relationships between day length and year length, and between month length and year length, after the intervention. Taken together with the data for the other two groups after the intervention, it is argued that this shows that the knowledge and understanding of these items is strongly related and interdependent i.e. that they are schematically related.

A further test, known as the Del test, enables the data in a 2 x 2 contingency table to be tested to see if knowledge of day length is a pre-condition for success in answering the question about month or year length. These coefficients are shown in table 7.6.5. The value of Del[1] varies from +1, which indicates that success on A is a total pre-condition for success on B, to -1 which indicates that the items are mutually exclusive, that is that failure on A is likely to lead to success on B.

A value for the significance of Del can be calculated, and in table 7.6.5 is shown by an * implying that the item is significant at $p<0.05$, ** implying significance at $p<.01$ and *** implying significance at $p<.001$. In reading the tables, there are two Del values provided for each item. Those indicating the dependence of the (correct) response to month length on the response to day length, the response to year length on month length and the response to year length on day length lie beneath the diagonal. Hence in the post-test, the Del value of 0.7, marked with an *(a)*, is high and significant indicating that a successful response to day length is a pre-condition for a successful response to the question about year length. Whereas, the del value for the converse relationship is 0.23, marked with a *(b)* which indicates that although there is a positive relationship

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1 Given two items to which the children's responses can be categorised into success (1) or failure (0), the cells of interest in a 2 x 2 contingency table become those where the child succeeded on one item but failed on another i.e. cells b and c.

Item B \ Item A	0	1
0	a	b
1	c	d

For instance, if cell b is low or 0, it means that success on A only happens for children who have succeeded in B so that it can be inferred that success on Item B is a pre-condition for success on item A. For instance, the following contingency table was obtained from Lower Juniors after the intervention for their responses to day length and month length.

Day \ Month	0	1
0	3	0
1	6	22

It shows that there were no children who succeeded in answering the question about the length of a month who had not succeeded in answering the question about day length. Conversely there are several children who are successful in answering the question about day length who fail to answer the question about the length of a month. The obvious inference from these data is that knowledge of day length is a prior construct to understanding the concept of a month.

between the responses to these two items, it is not significant. Hence the pre-condition for answering the question about year length is a correct answer to the question about day length.

Overall, the results show that prior to the intervention, there was no relationship of any significance between the infant responses. After the intervention, many of the relationships between the responses were significant and showed that there was a clear hierarchy where a correct response to year length was dependent on knowledge of month length which in turn was dependent on a knowledge of day length.

Pre

	Day	*Month*	*Year*
Day		0.29	0.15
Month	0.33		0.18
Year	0.56	0.57	

Post

	Day	*Month*	*Year*
Day		0.46*	0.23(b)
Month	0.81**		0.56**
Year	0.70** (a)	1.0***	

Table 7.6.5. Table of Del coefficients for infant children's responses to day, month and year length

Table 7.6.6. shows the same coefficients calculated for the lower junior children. It shows a similar pattern with little or no significance in the relationships prior to the intervention which then became highly significant after the intervention.

Pre

	Day	*Month*	*Year*
Day		0.15	0.02
Month	0.35		0.21
Year	0.14	1.00***	

Post

	Day	*Month*	*Year*
Day		0.30	0.13
Month	0.59**		0.26
Year	1.00***	1.0***	

Table 7.6.6. Table of Del coefficients for lower junior children's responses to day, month and year length

The data for upper juniors are shown in table 7.6.7. These are different in that a definite significant relationship between their responses did exist prior to the intervention with a clear hierarchy indicating that these concepts were well understood. The negative relationship between day and month after the intervention with a Del value of -0.18 is accounted for by the fact that 80% of children were successful on both items, a success rate so high that there is no significant relationship between the two items.

Pre

	Day	*Month*	*Year*
Day		0.21	0.16
Month	1.00***		0.25
Year	1.00***	0.33	

Post

	Day	*Month*	*Year*
Day		-0.05	0.25
Month	-0.18		0.49
Year	1.00***	0.59**	

Table 7.6.7. Table of Del coefficients for upper junior children's responses to day, month and year length

Finally, a paired t-test was conducted on an overall variable constructed from the data which is a measure of those who responded correctly or nearly correctly to all of the questions about day, month and year length. This showed a significant improvement ($p<0.05$) after the intervention for the lower juniors' understanding of the general concept of time as represented by this compound variable. The changes for infants and upper juniors were not significant as infant understanding improved only marginally whilst upper juniors had substantially assimilated the concept of time and its divisions.

7.7. What do children know about the movement of the Sun through the year?

If children are going to develop a model to explain seasonal differences, it follows that a basic requirement is that they should be aware of the major distinctions between the seasons. If not, from their perspective, there would be little need to engage in an exploration of what causes such events. Two questions (Question 1 and Question 2, Section B) attempted to elicit whether children knew of common seasonal changes. Children were asked to add the Sun to a drawing of a playground to show where it would be, firstly in winter at midday, and then in summer at the same time. There were two predominant features to their responses. Firstly whether the two responses were aligned vertically or horizontally, and secondly for those that showed the responses aligned vertically, whether the summer Sun was placed at a higher altitude than the winter Sun.

Fig 7.7.1 shows the predominant response showing the position of the Sun in both seasons at the same level given by all groups (infants 92%, lower juniors 48% and upper juniors 79%).

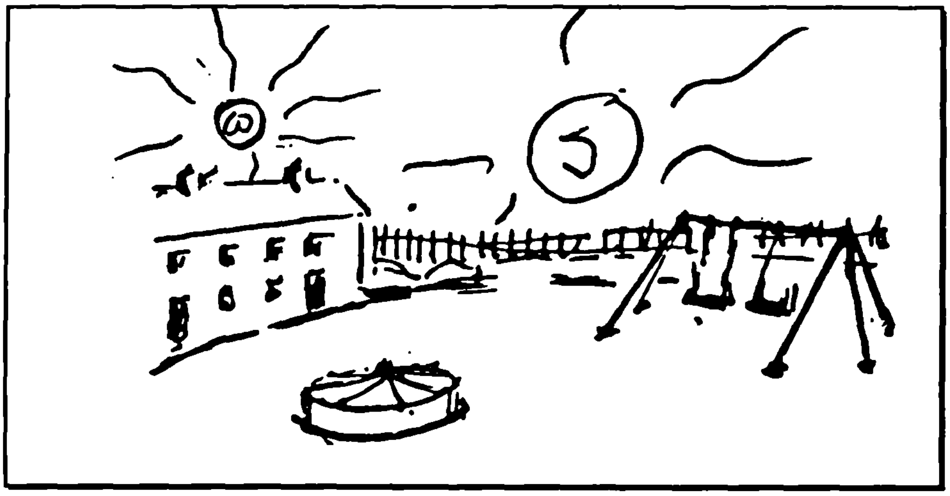


Fig 7.7.1: Typical response given by children to question asking to draw the position of the Sun in the middle of the day in the summer (S) and in winter (W)

The percentage giving the correct response was 8%, 29% and 8% respectively (infants, lower juniors, upper juniors) and after the intervention, this had only increased to 14%, 32% and 23%. These data show that very few children were aware of the difference in altitude of the Sun above the horizon between summer and winter. Since this observation and knowledge is an a priori necessity for the formulation of an explanation of the seasons, it is to be expected that only very few children would be able to offer a correct explanation. A common error in their responses was to show correctly the distinction as a difference in the vertical displacement but, with the Sun in winter shown as being higher than that in summer (Fig 7.7.2).

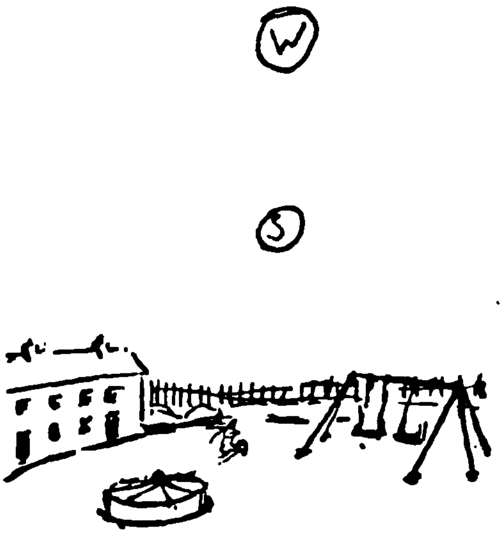


Fig 7.7.2: Response showing a vertical, but erroneous difference in position of the summer and winter Sun.

The data for all the responses are shown in table 7.7.1. The intervention has had a positive effect in improving the number who are familiar with the change in position of the Sun between summer and winter, none of the changes was significant and only a minority are capable of showing the correct relative positions. Moreover, there did not seem to be much of an apparent improvement across the age range. Collapsing the data into two groupings of 'vertical' and 'horizontal' does show that the number of upper juniors showing the Sun in different vertical positions increased and this was significant ($p<0.01$). However, the fact that only a low percentage seemed to be aware of a relatively simple observation of the variation of the Sun's altitude from winter to summer, which in itself is the basis for an explanation of the seasons, would imply that many of these children would have been incapable of giving any appropriate reason for the cause of the seasons.

	Inf-Pre %	*Inf Post %*	*LJ-Pre %*	*LJ-Post %*	*UJ-Pre %*	*UJ-Post %*
Vertically aligned and correct	8	14	29	32	8	23
Vertically aligned and incorrect	0	8	23	16	13	28
Horizontally placed on the same level	92	78	48	52	79	49

Table 7.7.1: Data for children's drawings of the Sun at midday in the summer and winter

Whilst it is not self-evident what makes this particular observation so difficult to assimilate, the data shows that the effect of the intervention was to increase the numbers of children who showed the distinction between summer and winter position of the Sun was in the vertical plane.

The other peculiar feature of the data is that there was no progression in children's understanding. The group that was most successful in responding to this item was the lower junior group, whilst the upper juniors had more difficulty in correctly answering this question. This result was abnormal in that the general trend for most items was for facility to increase with age.

Other seasonal differences between summer and winter

Children were asked if they could think of three differences between a summer day and a winter day. The overwhelming response that most children gave was that it was hotter in summer. At all ages more than 50% gave this response and typical answers were:

'It's windy in winter and cold. In summer it's hot and sunny.'

Mahfogur: Age 10

'Summer is hotter than winter.	Jaffrey: Age 10'
'Summer is different from winter because its colder in winter. Sometimes it snows and there's fog	Zeeshan: Age 8

However, there were a small minority who mentioned other attributes of seasonal differences.

'There is different weather, different lightness and it's different in dark. The time changes in winter. At 4 o'clock it's dark.'	Naheen: Age 10
'A summer day is hot. There are flowers. There is no snow.	Venetia: Age 11
'In winter the days are much shorter.'	Zarina: Age 11
'In winter the sun is quite down.'	Haroon: Age 7
'In summer we play outside, in winter we stay at home.'	Zilani: Age 6

In all, six differing responses were obtained. Summer days were hotter or vice versa, winter days were colder; people's clothing varied; summer days were longer; there were seasonal variations in foliage or plants and finally, activities were different in the summer i.e. people went on holiday, sunbathed etc. Fig 7.7.3 shows a summary of the children's responses indicating the percentage obtained in each category.

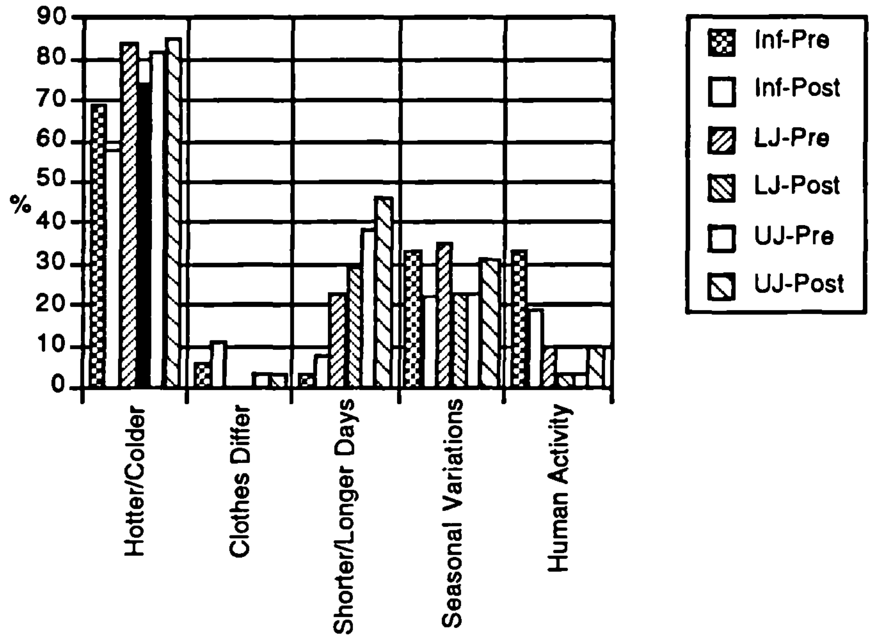


Fig 7.7.3: Chart showing the percentage of children giving each category of response to a question asking about seasonal differences for each age group pre- and post-elicitation.

The data also show that there was little variation between any of the age groupings, and between the pre- and post-elicitation, with the exception of the category of answers about the length of day. Here there was a steady improvement with increasing age in the number providing the correct response but there were no significant changes as a result of the intervention. However, the difference between infants and lower juniors prior to the intervention was significant ($p<0.05$), as was the difference between infants and upper juniors ($p<0.01$).

What are the implications of the data in Table 7.7.1 and fig 7.7.3. Taken independently of any other data, they indicate that only the most obvious seasonal differences registered with the majority of children, and that older children showed an increasing familiarity with the variation in day length between winter and summer, but that the intervention had little effect on their knowledge of the typical variations between seasons. Clearly such information is not something which impinges on children's minds readily. If so, it is possible that explanations for the seasonal variation are likely to be of little significance and meaning since they address physical phenomena that are not assimilated, possibly because the time scale of the variation is so large in terms of children's experience as to be meaningless.

For the lower and upper junior group, the data were examined to see if there was any agreement[1] between their responses for the difference in the height of the Sun between Summer and Winter and their responses for the length of day and the variation in temperature between the seasons. The data are shown in table 7.7.2a & 7.7.2b.

		Length of Day	*Seasonal Variation in Temperatures*
Pre	*Height of Sun (Summer /Winter)*	*-0.22*	*-0.35*
Post	*Height of Sun (Summer /Winter)*	*-0.03*	*0.03*

Table 7.7.2a: Table of G indexes of agreement for responses by lower juniors to question about height of Sun (winter/summer) and variation in day length and seasonal temperatures.

1 Using r_g as a measure of the index of agreement

		Length of Day	*Seasonal Variation in Temperatures*
Pre	*Height of Sun (Summer /Winter)*	*0.28*	*-0.13*
Post	*Height of Sun (Summer /Winter)*	*0.13*	*-0.33*

Table 7.7.2b: Table of G indexes of agreement for responses by upper juniors to question about height of Sun (winter/summer) and variation in day length and seasonal temperatures.

Calculations of Del values for both lower juniors and upper juniors show that the only relationship where there was a significant relationship was prior to the intervention for the upper juniors. For this group the data showed that knowledge of seasonal variation in temperature appeared to be a pre-condition for success in showing how the height of the Sun varied between the two seasons. However, such a relationship was not maintained after the intervention. The picture that emerges again is a lack of any defined relationship between these separate components of their knowledge. In fact the data show that there was a negative correlation between these two aspects of their knowledge in some cases. This would suggest that these children were operating with knowledge which is essentially fragmented and unrelated, and that knowledge of a physical phenomenon does not necessarily carry with it an understanding of a model which enables relationships and links to be made to other physical phenomena.

Data for an item which required the children to use models to explain how the Sun and Earth moved during the course of a year are shown in Fig 7.7.4. This chart shows the broadest features of their response divided into the categories of no response, one body moved or both bodies moved.

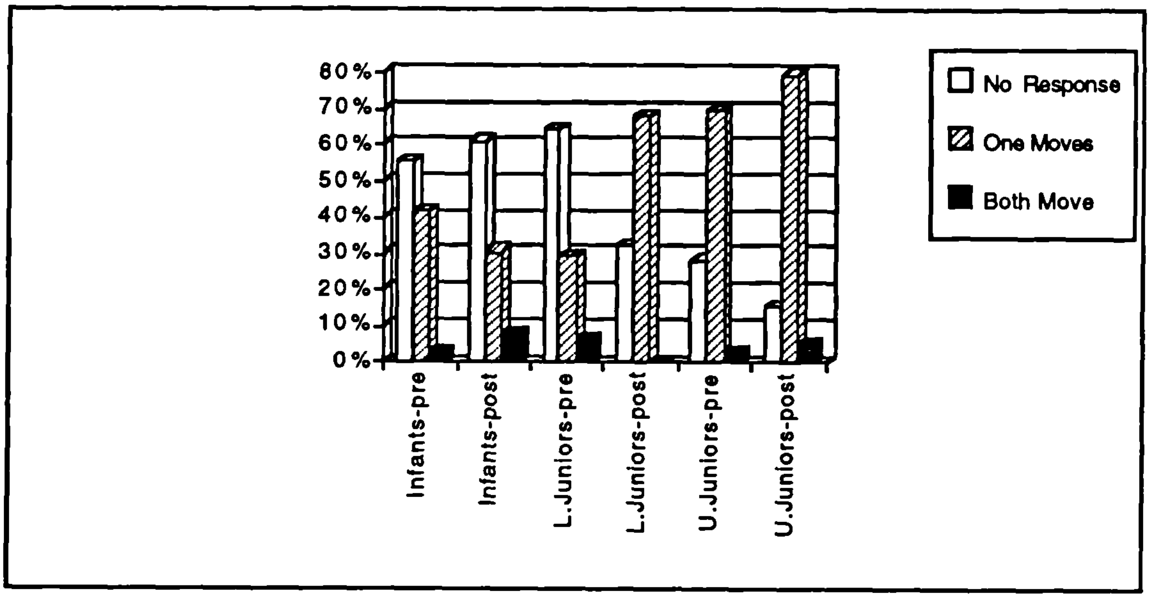
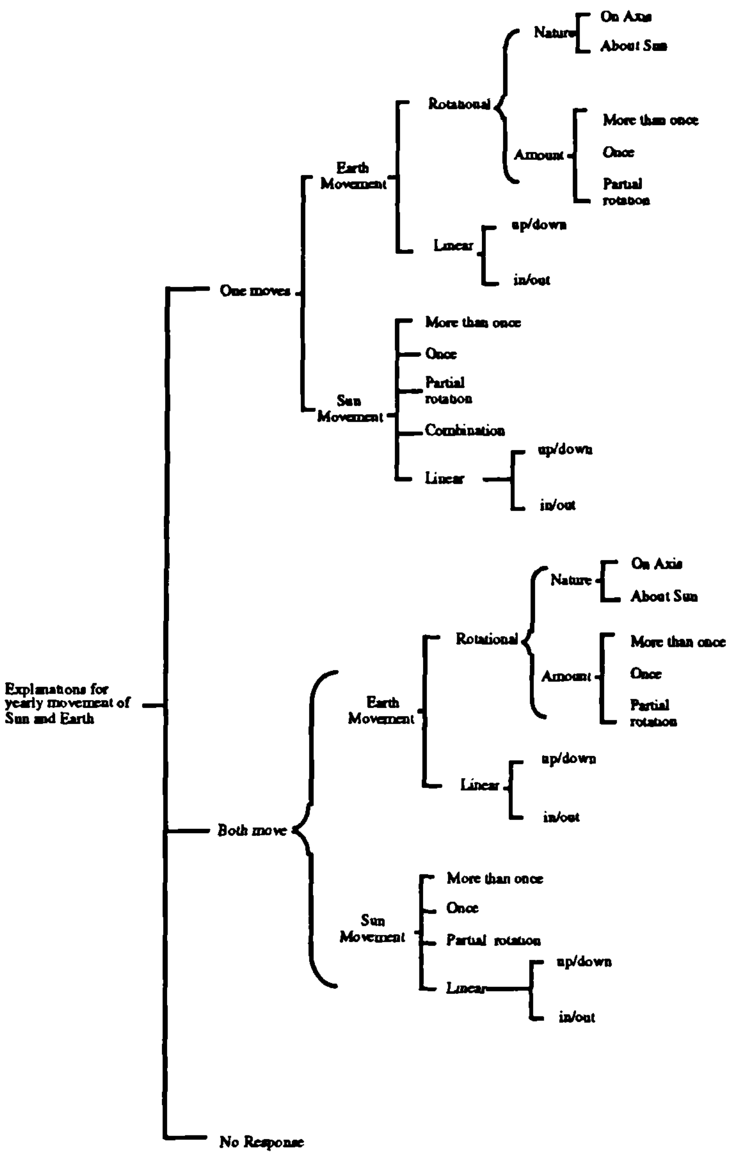


Fig 7.7.4: Data for children's explanation of the annual movements of the Sun and Earth.

The most noticeable feature was the significant transition that occurs as a consequence of the intervention in the understanding of the lower juniors. From a situation where the majority provided no response to this item prior to the intervention, it changed to one where the majority indicated that either the Earth or the Sun move. Thus the lower juniors improved to a position where, in broad terms, their understanding was similar to that of the upper juniors, prior to the intervention and this represented a significant change ($p<0.01$). None of the other changes was significant.

The data were analysed using a systemic network (Fig 7.7.5) which gives a picture of the range of explanations provided by children and the variation between groups. As indicated the broad division within the network is whether the child showed one or both bodies moving. Then within that, the network shows the details of the movement they ascribed to individual bodies. Whilst the network at first sight seems complex, the bottom half is really a replication of the top half to enable the categorisation of answers which stated that both bodies move. The data in Fig 7.7.5 show that only a minority did this. More importantly what these data show is the increasing number who provide the correct response that the Earth moves during the course of the year.



	Infant n=36		Lower Juniors n=31		Upper Juniors n=39	
	Pre	Post	Pre	Post	Pre	Post
One moves – Earth Movement – Rotational – Nature – On Axis	-	1	1	-	3	2
One moves – Earth Movement – Rotational – Nature – About Sun	3	6	-	16	18	27
One moves – Earth Movement – Rotational – Amount – More than once	-	2	-	5	4	2
One moves – Earth Movement – Rotational – Amount – Once	3	3	-	8	17	27
One moves – Earth Movement – Rotational – Amount – Partial rotation	-	2	1	3	-	-
One moves – Earth Movement – Linear – up/down	1	-	-	-	-	-
One moves – Earth Movement – Linear – in/out	4	1	1	-	1	-
One moves – Sun Movement – More than once	-	-	3	1	1	2
One moves – Sun Movement – Once	2	-	3	4	1	-
One moves – Sun Movement – Partial rotation	1	1	-		2	-
One moves – Sun Movement – Combination	-	-	1	-	-	-
One moves – Sun Movement – Linear – up/down	3	-	-	-	-	-
One moves – Sun Movement – Linear – in/out	1	2	-	-	1	-
Both move – Earth Movement – Rotational – Nature – On Axis	1	1	1	-	1	-
Both move – Earth Movement – Rotational – Nature – About Sun	-	-	-	-	-	2
Both move – Earth Movement – Rotational – Amount – More than once	1	1			1	1
Both move – Earth Movement – Rotational – Amount – Once	-	-	-	-	-	1
Both move – Earth Movement – Rotational – Amount – Partial rotation	-	-	1	-	-	-
Both move – Earth Movement – Linear – up/down	-	1	-	-	-	-
Both move – Earth Movement – Linear – in/out	-	1	1	-	-	-
Both move – Sun Movement – More than once	1	1	-	-	-	-
Both move – Sun Movement – Once	-	-	-	-	1	1
Both move – Sun Movement – Partial rotation	-	-	1	-	-	1
Both move – Sun Movement – Linear – up/down	-	-	1	-	-	-
Both move – Sun Movement – Linear – in/out	-	2	-	-	-	-
No Response	20	22	20	10	11	6

Fig 7.7.5: Network used to categorise children's responses to the question asking them to show with their shapes how the Earth or Sun moved during a year.

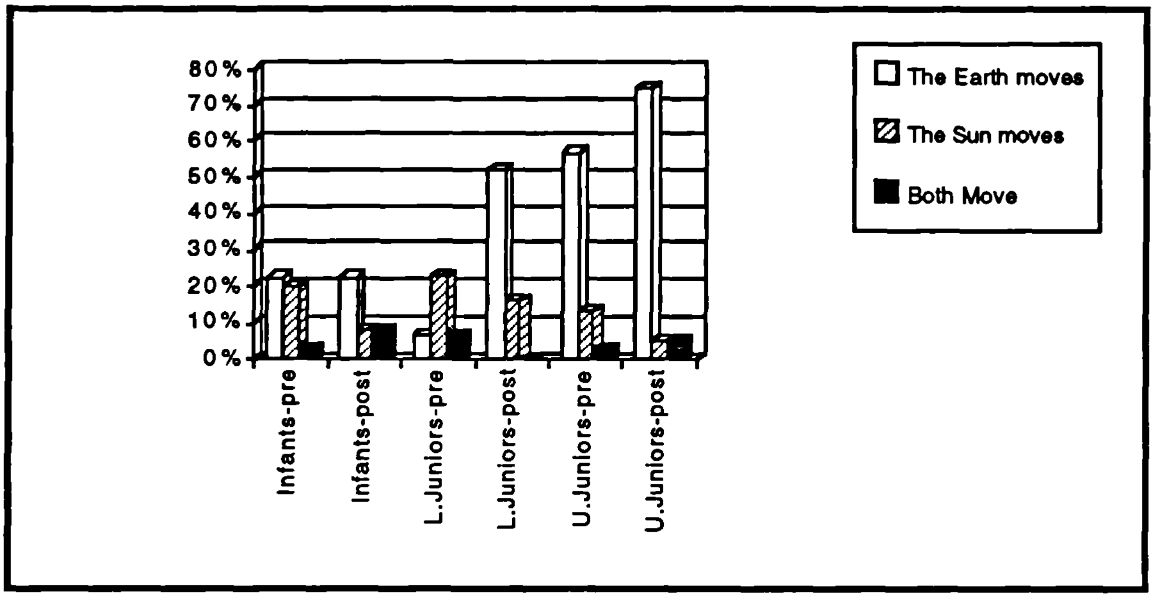


Fig 7.7.6: Chart showing the percentage of the children indicating which body moved when explaining what happens to the Earth and Sun during one year.

Fig 7.7.6 also shows clearly that there was a minority of children who thought that it is the Sun which moves and that this group only declines in the upper juniors. At all ages, the percentage who said that both move was relatively small. The main change occurred with the lower junior group as a consequence of the intervention, where the percentage who gave the scientific response that the Earth goes round the Sun rose from 6% to 52% which was significant ($p<0.01$). The major effect of the intervention would seem to have been to raise the level of understanding of this group near to that demonstrated by the upper juniors prior to the intervention. Again the chart does not represent a developmental sequence as this was not a longitudinal study but it does at least indicate that it was children of age 8/9 years who were the youngest children who could successfully assimilate the scientific explanation. For infants and upper juniors the intervention only had marginal improvements and, for the latter group, it would seem that by the age of 10/11 the majority of children have already assimilated the Copernican world view. In view of the lack of direct concrete evidence for such a view, this result is in many ways quite remarkable.

Table 7.7.3 shows the number of pupils in each grouping who gave the features of a scientific response i.e. that the Earth a) moves about the Sun, and b) does so once in a year. The data show that there has been a significant ($p<0.01$) improvement in the number of upper and lower junior children holding the Copernican world view of the annual movement of the Earth around the Sun. Also they show that the idea the Earth moves was sometimes established for younger children before a clear conception of how often it moves. In addition there is a clear correlation ($r_{g_{LJ\text{-}post}} = 0.48$; $r_{g_{UJ\text{-}pre}}=0.89$; $r_{g_{UJ\text{-}post}} = 0.97$) between these two aspects of knowledge which in all cases was highly significant ($p<0.01$). This would then suggest that once the child accepts the scientific view that the Earth moves, the information about how long it takes is also assimilated at more or less the same time.

	Inf-Pre (n=36)	*Inf-Post (n=36)*	*LJ-Pre (n=31)*	*LJ-Post (n=31)*	*UJ-Pre (n=39)*	*UJ-Post (n=39)*
Earth moves about the Sun	3	6	0	16	18	27
Earth moves about the Sun and moves once in a year	3	3	0	8	17	27

Table 7.7.3: Numbers giving features of a correct scientific response in explaining how the Earth and Sun move during the course of one year.

The question then arose as to whether children were capable of using the information about how the Earth moved to explain the variation in day length and temperature with season. Exploring this aspect of their understanding was performed in two parts. Firstly the children were asked if they could explain with their shapes or by drawing, why the day is longer in summer (Question 2(a), section D) and then, why it is hotter in summer (Question 2(b), section D). The data obtained for children's responses to the first question are shown in table 7.7.4. Data on this item were not collected from infants as the pilot exploration had shown that such questions had little meaning for this group of children.

In this area, the suggested intervention activities to explore children's understanding were based around discussion of simple propositions about the movement of the Sun and Earth and a set of activities asking children to act out the movement of the Sun and Earth. Children's responses were categorised in three groups - those that showed a partial scientific explanation in that they mentioned that the Earth is tilted or that the Sun is higher in the sky; those that were scientifically incorrect, and those that gave no response. The results show that the number of children providing an explanation mentioning aspects of the full scientific explanation increased as a consequence of the intervention and both sets of changes were significant ($p<0.05$). Some of these explanations were the full scientific explanation making good use of their model to show that the earth's axis is tilted which results in an enhanced day length for half the year and diminished day length for the other half. However such explanations were relatively rare and have therefore not been counted separately.

Cross-tabulations of children's explanations for why day length varies with their models for the motion of the Sun through the year showed that a) there was a significant relationship between the two ($p<0.05$) both pre- and post-intervention and that b) success at explaining the variation was dependent on assimilating a Copernican model of how the Sun moves during the course of a year ($p<0.05$). The implication of this for teachers is that the Copernican model is an essential pre-requisite to developing an explanation of the variation between seasons.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Partial Scientific Explanation	-	-	0	19	21	49
Scientifically incorrect	-	-	61	48	46	28
No response Don't Know	-	-	45	32	33	23

Table 7.7.4: Data summarising the nature of children's explanations with models for why the day length varies throughout the year.

The second part of this question asked children if they could use their models to explain why it is hotter in summer than in winter. The data for children's responses were categorised into four groupings: those that explained that the Sun was nearer in summer; those that used climatic reasons e.g. the Sun is hotter in summer which is essentially a tautology; those that were unable to explain or gave no response and those that gave other reasons. The data for their responses are shown in Table 7.7.5.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Sun nearer	-	-	55	68	44	56
Climatic	-	-	23	16	23	13
No Response/Don't Know	-	-	23	16	28	28
Other	-	-	0	0	5	3

Table 7.7.5: Data summarising the nature of children's explanations with models for why the days are warmer in summer.

The main feature of the data was a lack of any change from one group to another as a consequence of the intervention. The naturalistic explanation that the rise in temperature in the summer is due to the closer proximity of the Sun predominated, as it does notably with adults. This is clearly an idea with an inherently powerful logic which appeals to intuition. Furthermore, the scientific explanation requires the appreciation and understanding of three factors: the annual movement of the Earth round the Sun; the tilt of the Earth's axis and the effect of the combination of the latter on the insolation (energy received per m^2) on the ground. Therefore, it was not surprising that it was not offered by any children, and that even adults find it difficult to articulate. The results would indicate that either this concept should be left out of any formal teaching within the primary school or, alternatively, only aspects of the explanation should be dealt with i.e. the annual movement of the Earth or the tilt of its axis but that the combination of the three is conceptually too difficult.

7.8. What explanations do children give for the phenomena of day and night?

Two questions were used to elicit the explanations that children gave for the origin of day and night. The first question (Question 3(a), section A) simply asked children what happened to the Sun at night.

The answer to the first question produced a range of responses of which the following are typical and reflect similar responses found by Piaget (1929).

'It goes away.'	Victoria: Age 7
'The Earth turns round and it blocks the Sun's way so that it is dark.'	Nazia: Age 8
'The Sun goes down and the moon comes up.'	Romana: Age 9
'It stays down behind the mountains.'	Haroon: Age 7
'It changes into a moon.'	Aaron: Age 9
'It is hidden by other planets and our moon.'	Venetia: Age 10

Older children tended to produce the scientific response or a version of it. However some of these responses display a geocentric view of astronomical movements.

'Goes to America, then goes round the world.'	John: Age 11
'It goes to the other side of the Earth.'	Yazdan: Age 10
'We cannot see it cos we turn away from it.'	Kelly: Age 10

'Because the earth moves, the earth faces away from the Sun.' Naheen: Age 11

The explanations were categorised into the following groups: simple explanations which stated that the Sun goes down; those which said that the Sun moves round to the other side; explanations which said that the Earth moves or turns on its axis and explanations which said that the Moon/clouds cover the Sun. 6% of lower juniors prior to the elicitation also gave no response. A summary of the data is shown in Fig 7.8.1 (a) & 7.8.1 (b)

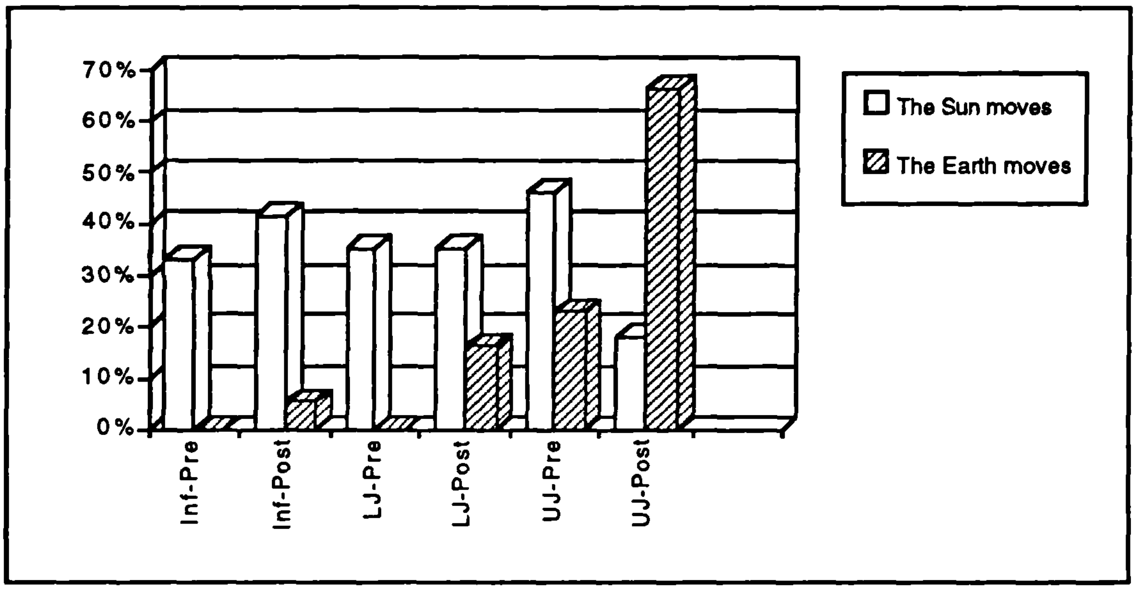


Fig 7.8.1a: Chart showing percentage of children indicating which body moved in response to question asking what happens to the Sun at night.

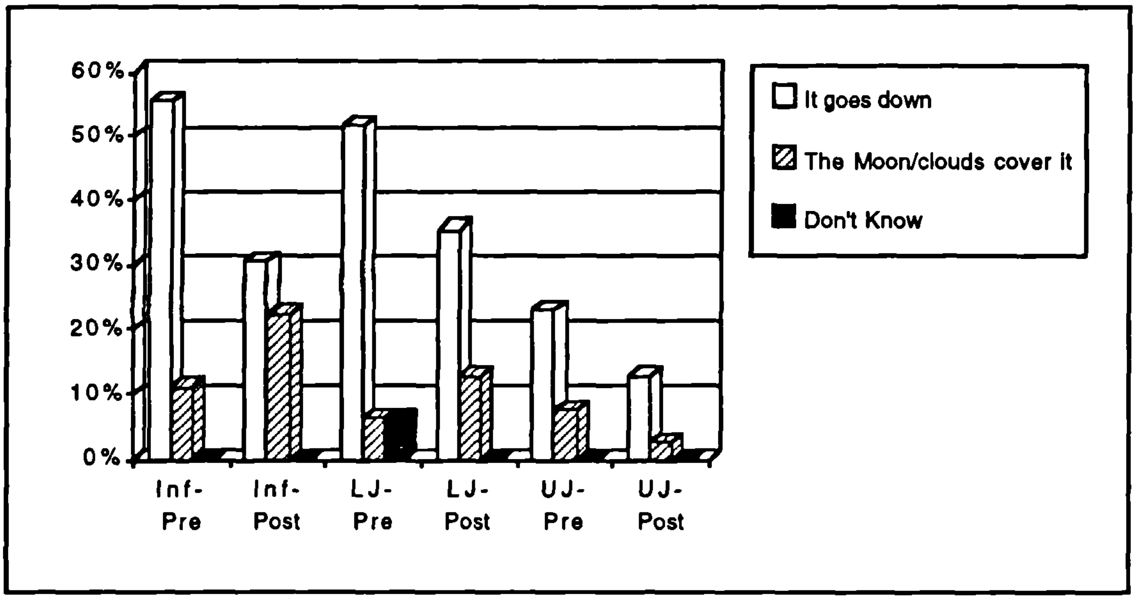


Fig 7.8.1b: Chart showing percentage of children giving other responses to the question asking what happens to the Sun at night.

Fig 7.8.1b reveals some quite interesting trends in children's responses. Firstly the number giving the typical response found by Piaget, that clouds cover the Sun, was a minority. Whilst this response was greatest with the infant children, it never exceeded 25% and steadily declined. The number who indicated the scientific view, that the Earth turns on its axis (Fig 7.8.1a), was zero prior to the elicitation for both the infants and lower juniors. The intervention had the effect of increasing this response for all three groups though the change was only significant ($p<0.01$) for the upper juniors. The two most commonly expressed ideas by all groups, except the upper juniors after the elicitation, was that the Sun simply goes down or alternatively, that the Sun moves. The latter response was often qualified by the statement that it went to the other side of the Earth. It could be argued that since this conception requires the child to conceive of a world around which the Sun rotates, it represents an advance on the simplistic notion of a Sun going down and is part of a developmental sequence that children may go through.

The second part of this question probed children's answers a little further by asking children if they could explain why night happens. Responses to this question were essentially of a personal nature i.e. 'so that I can go to sleep' which have been reported by Piaget (1929) or a physical nature i.e. 'because the Earth spins away from the Sun'. Some children also gave no response. The data for their responses are shown in Table 7.8.1.

The egocentric personal response diminishes across the age groupings although the intervention has had little effect in changing such responses from the infant grouping where over two thirds provide such a response. This general trend was accompanied by an increase in the number of children who gave a response based in physical phenomena, and the intervention has had a significant effect ($p<0.05$) for both the lower and upper juniors in increasing the number who provided this response. Significant differences did exist prior to the intervention between the responses of the infants and the upper juniors to this question. The outcome of the intervention has been to increase the differences in their understanding so that again, the lower juniors attained one similar to the upper juniors whilst the infants' understanding remained static. Hence the distinction between the infants and the other two groups' answers after the intervention had become highly significant ($p<0.01$).

Children were also asked to use the models they had selected to represent the Sun and the Earth (Question 1(b), section D) to show what happens during one day and night. A wide variety of responses was obtained and these were analysed using a systemic network shown in Fig 7.8.2.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Personal	64	75	42	29	38	26
Physical	14	14	23	52	44	69
Don't Know/No response	22	11	35	19	18	5

Table 7.8.1: Data for children's explanations for why night happens.

Table 7.8.2 shows a summary of the nature of children's responses at the most general level of categorisation in the network i.e. the categories on the left-hand side. At this level, the main feature of interest is how many children gave explanations which indicated only one body moved. The data show that such children were in a majority, even with the infant children, and that the numbers giving such an explanation improved with the intervention and across the age range. The change for the lower juniors was significant ($p<0.05$).

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
One Moves	58	69	65	90	79	97
Both Move	11	17	26	10	10	0
No Response	31	14	10	0	10	3

Table 7.8.2: Data for children's responses using models to explain how day and night happens.

Moving to the next level of delicacy, Fig 7.8.3 shows the percentage of children who gave the scientific response that it is the Earth that moves and the other attributes of the scientific explanation i.e. that it spins on its axis and rotates once.

Children's explanations of the daily movement of the Sun and Earth

	Infant n=36 Pre	Infant n=36 Post	Lower Juniors n=31 Pre	Lower Juniors n=31 Post	Upper Juniors n=39 Pre	Upper Juniors n=39 Post
One moves – Earth Movement – Rotational – Nature – On Axis	4	2	6	10	16	23
One moves – Earth Movement – Rotational – Nature – About Sun	2	8	6	11	4	6
One moves – Earth Movement – Rotational – Nature – Both	1		1	2	1	3
One moves – Earth Movement – Rotational – Amount – More than once	-	1	2	1	1	1
One moves – Earth Movement – Rotational – Amount – Once	5	5	8	15	18	23
One moves – Earth Movement – Rotational – Amount – Partial rotation	2	4	3	7	2	8
One moves – Earth Movement – Linear – up/down	-	-	-	-	-	-
One moves – Earth Movement – Linear – in/out	1	1	-	-	-	-
One moves – Sun Moves – More than once	-	2	-	1	-	-
One moves – Sun Moves – Once	-	-	3	2	6	5
One moves – Sun Moves – Spins on axis	-	-	-	-	1	
One moves – Sun Moves – Partial rotation	3	5	1	1	2	1
One moves – Sun Moves – Linear movement – up/down	6	7	3	0	1	-
One moves – Sun Moves – Linear movement – in/out	4	-	-	1	-	-
Both Earth & Sun move – Earth Movement – Rotational – Nature – On Axis	1	1	4	2	4	-
Both Earth & Sun move – Earth Movement – Rotational – Nature – About Sun	1	4	3	1	-	-
Both Earth & Sun move – Earth Movement – Rotational – Amount – More than once	-	1	1	1	1	-
Both Earth & Sun move – Earth Movement – Rotational – Amount – Once	2	-	5	2	2	-
Both Earth & Sun move – Earth Movement – Rotational – Amount – Partial rotation	-	4	1	-	1	-
Both Earth & Sun move – Earth Movement – Linear – up/down	-	-	-	-	-	-
Both Earth & Sun move – Earth Movement – Linear – in/out	2	1	1	-	-	-
Both Earth & Sun move – Sun Moves – More than once	-	-	-	-	-	-
Both Earth & Sun move – Sun Moves – Once	-	-	3	-	-	-
Both Earth & Sun move – Sun Moves – Spins	1	-	1	1	-	-
Both Earth & Sun move – Sun Moves – Partial rotation	1	4	1	1	1	-
Both Earth & Sun move – Sun Moves – Linear – up/down	2	1	2	0	2	-
Both Earth & Sun move – Sun Moves – Linear – in/out	-	1	1	-	1	-
Both Earth & Sun move – Sun Moves – Combination of spin and rotate	-	-	-	1	-	-
No Response	11	5	3	0	4	1

Fig 7.8.2 Network for the analysis of children's explanations using models of how the Sun/Earth or both move in one day and night.

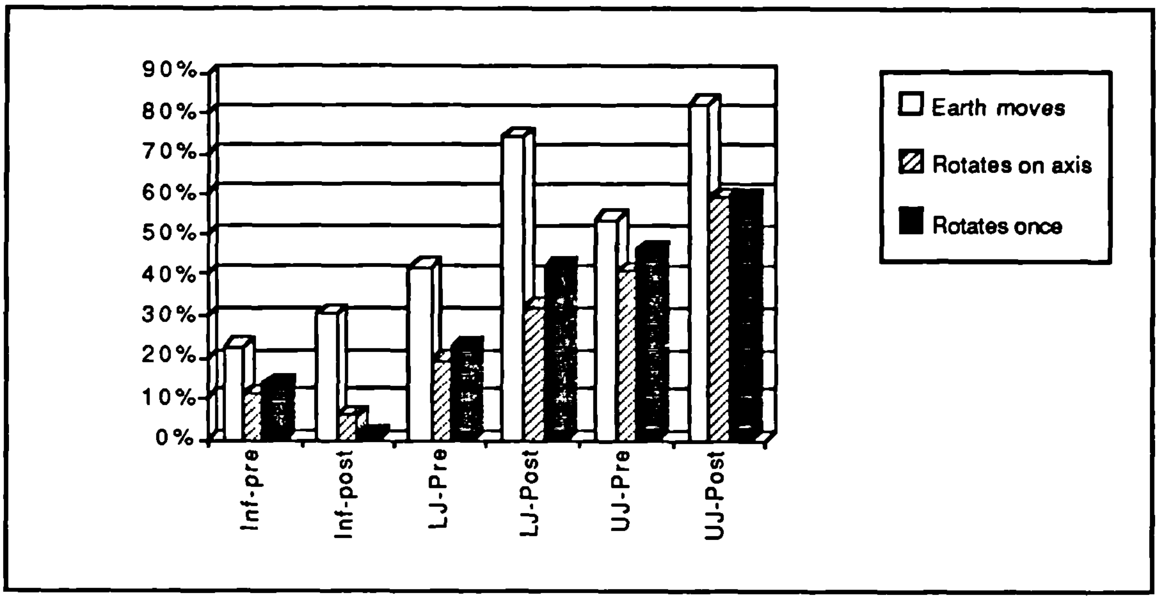


Fig 7.8.3: Chart showing the percentage of children who gave the response that it is the Earth which moves and other attributes of the scientific explanation for the phenomena of day and night.

The data show that there was a change in the numbers indicating that it is the Earth which moves and positive increases in this response for all groups as a consequence of the intervention. For both the lower and upper juniors, these changes were highly significant ($p<0.01$). The numbers giving the full attributes of the scientific explanation, that the Earth spins and spins on its axis once, increased from 36% to 46% for the upper juniors ($p<0.01$), from 10% to 19% for the lower juniors and only the infants group showed a decrease in the number of children giving aspects of the scientific response after the intervention from 8% to 6%. Infants who did say that the Earth moved predominantly stated that it moved about the Sun and this response would suggest that there was an unresolved confusion in their minds. Possibly the intervention had introduced the idea that the Earth moves but either, the daily and annual movements were confused, or the idea that the Earth moves about the Sun was acceptable to these children in providing an explanation for the apparent motion of the Sun. Hence what the data show is the possibility that such children were operating with proto-concepts, that is concepts which are an amalgam of aspects of detail from a wide range of sources.

The major response that infant children gave was the naturalistic explanation that it is the Sun which moves. However, the data show that by the age of 8/9 this was not the dominant explanation and the idea that it was the Earth that moved had become the predominant explanation offered by lower juniors prior to the intervention. The data also show that the idea of the Sun moving was maintained or held by a significant minority of children throughout the age range and that such thinking was not easily changed.

The data were examined to see what relationship existed between the children's responses to the question asking what happened to the Sun at night, and their models of the daily motion of the Sun and Earth. Somewhat surprisingly there was no correlation of any significance between children who, in the former question, gave responses indicating that the Earth moved on its axis and those children whose model of the daily motion of the Earth was the scientific one. Similarly there was no correlation between those children who gave responses based on physical phenomena to the question 'Why does night happen?' and those who held the scientific model of the daily motion of the Earth. In the case of the infant children, such small percentages gave either a physical response or a model compatible with the scientific world view, that this is not remarkable. However, in the case of the upper juniors, it would indicate that the items are seen as separate items of knowledge with little or no interdependence.

7.9 What do children know about the daily movement of the Sun and related phenomena?

7.9.1 The Daily Movement of the Sun

This is an aspect of knowledge expected from children by the National Curriculum. In addition, it is one of the simplest phenomena to observe and must be applied to explain the workings of a simple sundial. The research therefore attempted to investigate what knowledge children had of this everyday event and whether they could apply it in explaining how the sundial actually worked.

The first question (Question 2, section A) utilised a drawing to which children were asked to add to show the Sun on their way to school, at midday and on the way home from school. The drawing is shown in Appendix 7a and reflects the typical environment of the pupils who were the subject of this study.

A response that was judged to be correct is shown in Fig 7.9.1.1. This shows the correct sequence, with the Sun rising in the East and setting in the West, with the midday Sun shown at a higher elevation above the horizon than either the morning or afternoon Sun.

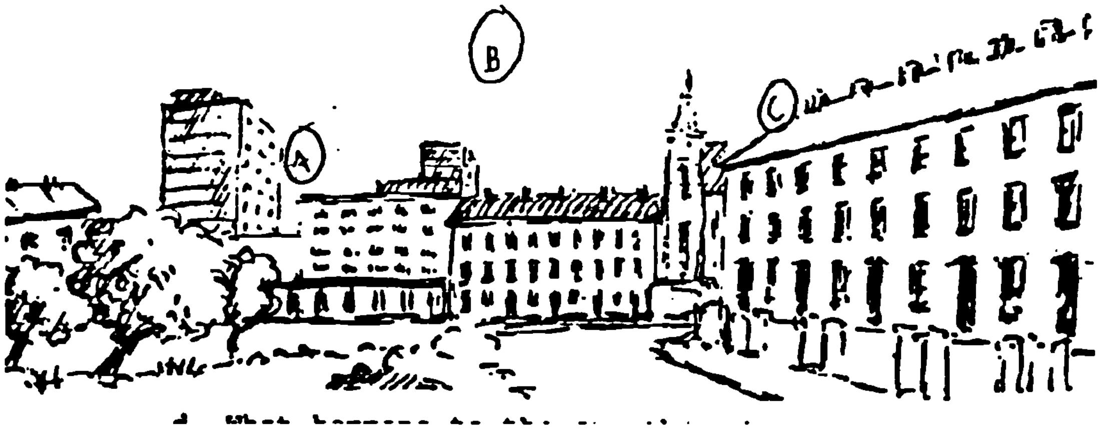


Fig 7.9.1.1: Correct response to question asking children to show the position of the Sun during the morning, midday and afternoon.

However, this type of response, showing the correct sequence and the correct relative height at midday, was only provided by 6% of infants, 20% of lower juniors and 10% of upper juniors. The low facility on this item was somewhat surprising given that this is a simple observation which children of these ages would have had plenty of opportunity to make. A large proportion of the responses showed the Sun moving in the correct direction, from East to West, but without any variation in the altitude of the Sun above the horizon. Such an example is shown in Fig 7.9.1.2.

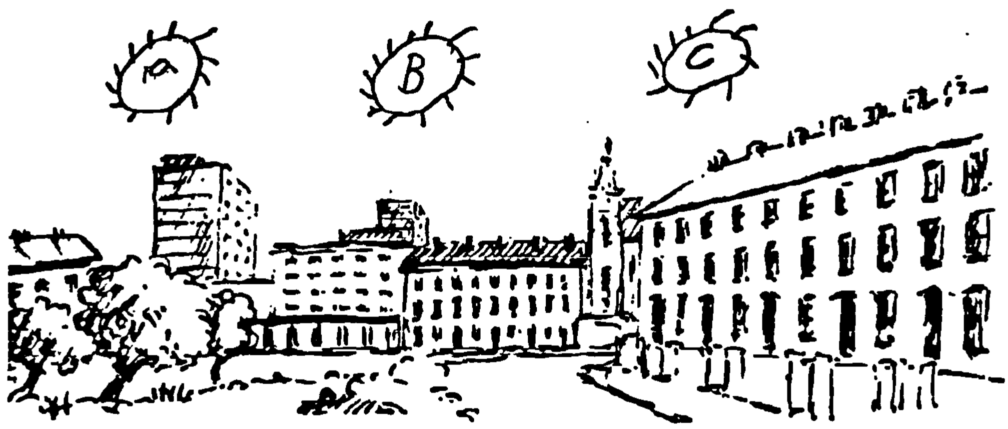


Fig 7.9.1.2: Typical incorrect response to question asking children to show the position of the Sun during the morning, midday and afternoon.

A significant percentage of the children (11% of infants, 19% of lower juniors and 26% of upper juniors) showed the sequence of the daily movement of the Sun in the reverse order from West to East as shown in Fig 7.9.1.3.

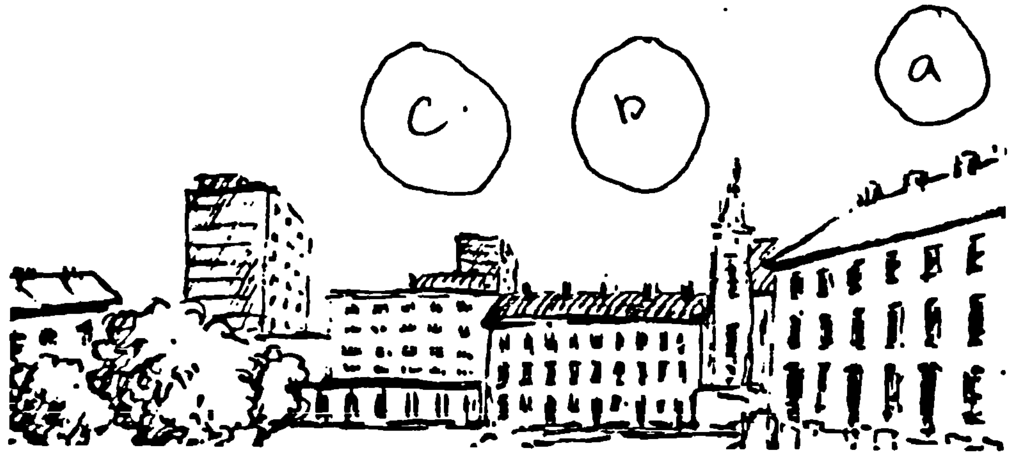


Fig 7.9.1.3: Response to question asking children to show the position of the Sun during the morning, midday and afternoon showing Sun moving from West to East.

The third type of error (Fig 7.9.1.4) was simply to show the three positions of the Sun in a vertical sequence though this was only done by small minorities of infants (6%), no lower juniors (0%) and upper juniors (23%).

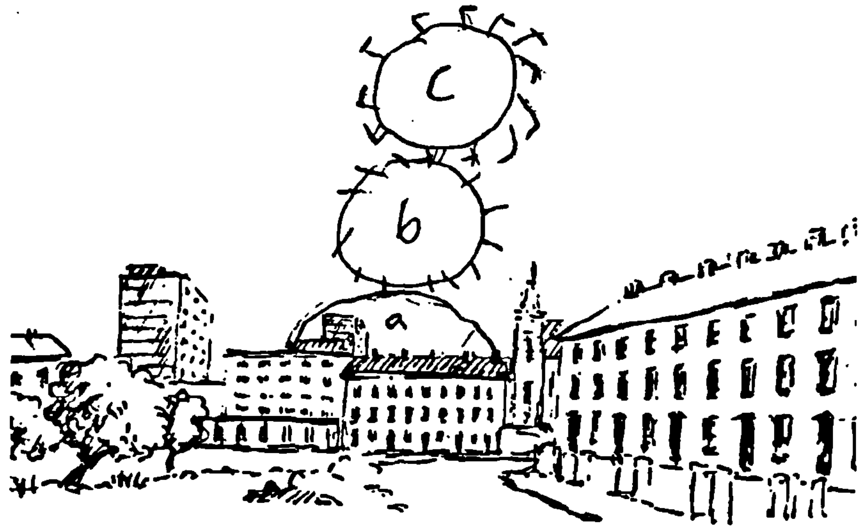


Fig 7.9.1.4: Response to question asking children to show the position of the Sun during the morning, midday and afternoon showing Sun placed in a vertical sequence.

Children's drawings show two aspects of particular interest, the *sequence* in which they place their position of the Sun, e.g. left to right, or alternatively right to left, and the *level* of the Sun above the horizon. The possible responses are best summarised by a simple network shown in Fig 7.9.1.5.

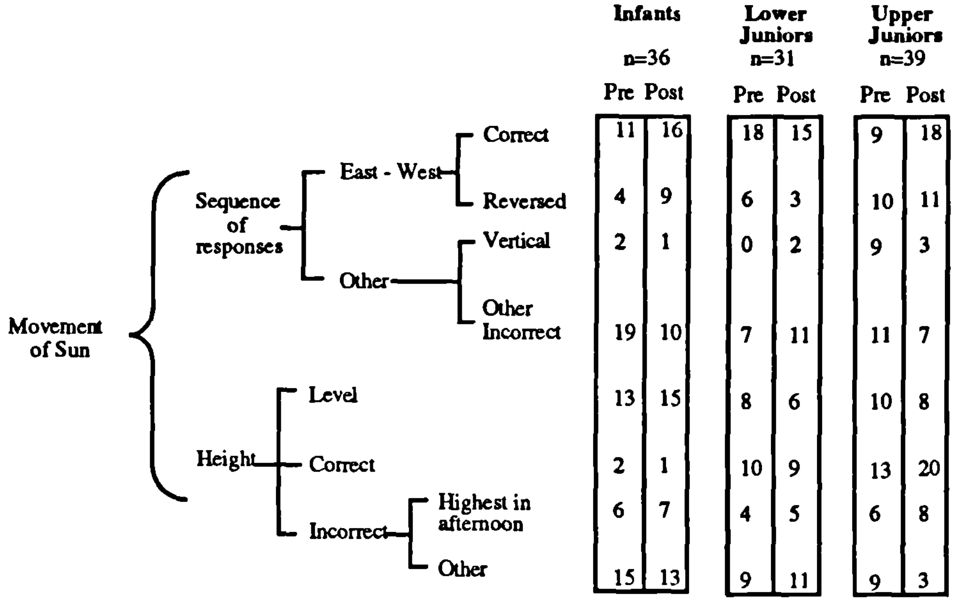


Fig 7.9.1.5: Network for analysis of children's drawings to show the position of the Sun during the day.

The data for the component of children's responses dealing with sequence are also shown in Table 7.9.1.1. The most noticeable features of the data are twofold; firstly, the lack of any really clear improvement in children's knowledge and understanding of the correct sequence and secondly, the fact that it was generally a minority of all children who were capable of showing the correct sequence. Both the infants and upper juniors did show an improvement in their knowledge and the change for the latter group was significant ($p<0.05$) but the lower juniors' understanding seems to have regressed. A contingency table analysis of the lower juniors' responses pre-intervention against those post-intervention shows that only 23% of the sample consistently gave the correct drawing of the sequence of the daily motion of the Sun.

Sequence	*Inf-Pre* %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Correct	31	44	58	48	23	46
Reversed	11	25	19	10	26	28
Vertical	6	3	0	6	23	8
Other incorrect	53	28	23	35	28	18

Table 7.9.1.1: Percentage of children giving each category of response for the sequence of the Sun's daily movement.

The remaining variation was accounted for by the large number of children who moved from providing an erroneous view pre-intervention, to the correct drawing post-intervention and vice versa. For upper juniors, the number giving a correct drawing of the sequence, pre- and post-intervention was even lower at 10% and this means that the intervention may have led to the improvement of 36% in the number of upper juniors giving the correct response.

These data needs to be examined in conjunction with those for the height of the Sun above the horizon (Figs 7.9.1.6a & 7.9.1.6b) which tend to confirm that the daily movement of the Sun is not a well-understood phenomenon. For instance, only for the upper juniors were a majority able to show the correct height of the midday sun above the horizon. There were a large percentage of responses which either showed the Sun in a level sequence or alternatively, with it in the highest position late in the afternoon. None of the changes after the intervention were significant and only the upper juniors showed a marked improvement in their understanding. These data would suggest that the difficulty of this topic may have been underestimated and had not been fully addressed by the intervention.

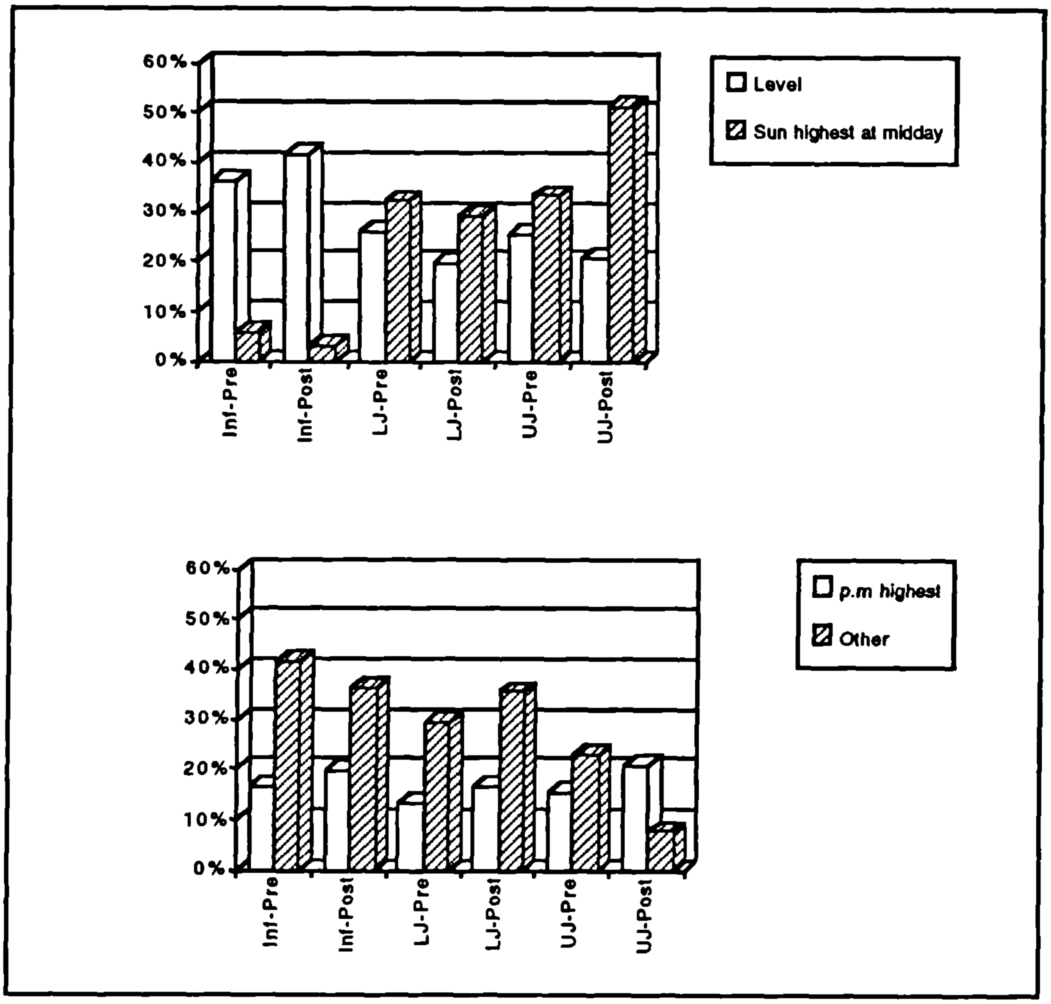


Fig 7.9.1.6a & 7.9.1.6b: Charts showing percentage of children providing each type of response for the height of the Sun during the day.

Table 7.9.1.2 shows the percentage of children who gave the correct response for the sequence of the Sun's daily movement and for the height above the horizon. It would seem that the success rate on this item is surprisingly low, given that a correct response is simply dependent on observation and assimilation of a daily phenomenon. Infants were notably weaker than lower or upper juniors and only a very small minority were consistently able to correctly respond to this item in both the pre- and post-elicitation. The positive effect of the intervention was to significantly improve the understanding of this event for the upper juniors, although with only 31% obtaining the correct result after the intervention.

In addition, comparing the responses to this question with those for question 1, section D which asked the child to use models to describe the daily motion of the Earth, it was found that holding a scientific model of the daily motion of the Earth was a precondition for providing the correct description of the daily movement of the Sun across the sky (Del = 0.54, p<.01).

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Correct Sequence and Correct Height	6	3	20	23	10	31
% giving same result pre- and post-intervention		3		10		8

Table 7.9.1.2: Data showing percentage of children in each age group who were able to show the correct sequence and correct relative heights for the Sun's daily movement.

For all groups, the correlation between their answers for the sequence and height of the Sun was calculated. There was no significance in the relationships between the two prior to the intervention for any of the groups. After the intervention, there was a correlation for the upper juniors ($r_g = 0.28$, just failing significance at $p<0.05$) and the lower juniors ($r_g = 0.35$, $p <0.05$). The lack of correlation between the two prior to the intervention clearly shows that a child could get one part of this question correct whilst getting the other wrong. This is again suggestive of a fragmented knowledge which fails to relate the two aspects. The intervention would appear to have had some success for the upper juniors in developing a more unified understanding of this phenomenon. Why children found this item difficult is unclear. Possibly the drawing showing an urban environment was difficult for them to interpret and the errors are those associated with a lack of perspective and drawing skills rather than any lack of knowledge. It is also possible that living in such an environment makes it difficult to note the regular repetition of the Sun's movement across the horizon.

The low facility and the somewhat erratic nature of the responses obtained from this item raise some doubts about its validity and it would have been interesting to compare responses to this item with drawings added to a flat horizon to explore the validity of the item or to use the same drawing with rural children to examine its reliability.

7.9.2. Children's understanding of shadows

A knowledge of the daily movement of the Sun is necessary to predict and explain the appearance and behaviour of shadows throughout the day. To explore their knowledge and understanding of shadows, children were given a drawing showing the Sun, a tree and its shadow early in the morning. They were then asked to add to this to show the position of the shadow at midday (Question 3, section B).

There was a wide range of responses to this question. At the lowest level, over and above no response at all, children simply added shapes to the drawing which were detached from the tree, bore no similarity to its shape and no relationship to the position of the Sun. Fig 7.9.2.1 shows a slightly better response of an infant child who sees no relationship between shadow, tree and Sun other than a vague attempt to draw something which has an equivalent shape.

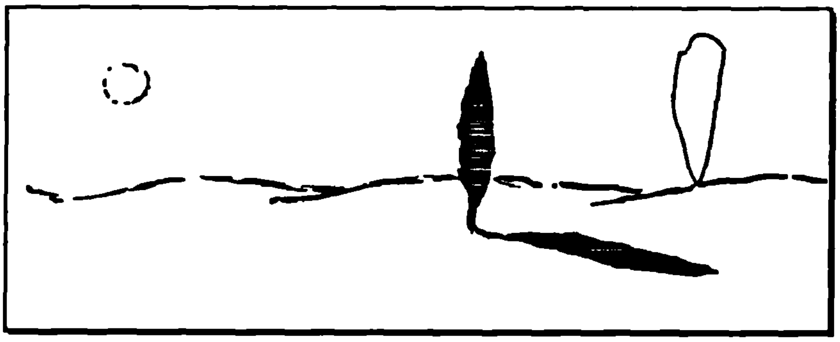


Fig 7.9.2.1: Response to question asking child (age 6) to show the position of the Sun at midday.

Another common error was to show the shadow in the correct position but no shorter or vice versa, a shorter shadow but in the wrong position. Fig 7.9.2.2 and Fig 7.9.2.3 show examples of both such responses.

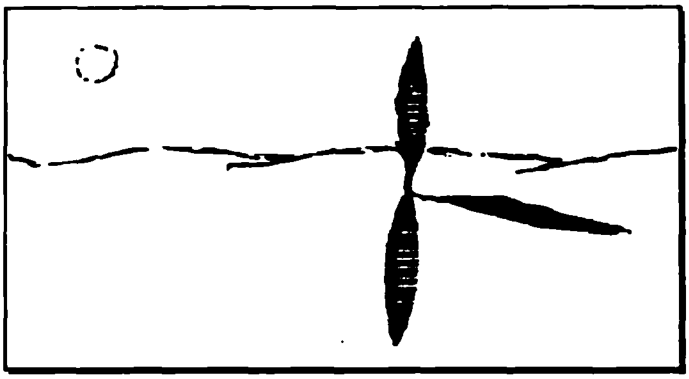


Fig 7.9.2.2 Response to question asking child (age 9) to show the position of the shadow at midday.

The number of children who responded to this question with the correct scientific interpretation showing the shadow shorter and towards the north was 19% of infants, 19% of lower juniors and 51% of upper juniors. The much higher success rate on this question contrasts notably with that on the previous one, particularly since this question makes more substantive cognitive demands on a child. For, to provide the correct response, he or she would have had to know that the midday sun has a higher altitude and been able to argue in terms of a compensation, i.e. as the Sun gets higher, the shadow goes shorter and as the Sun goes one way, the shadow goes the other way. Then, these two pieces of reasoning have to be combined to produce the correct answer. Thus the question raised by this item is whether the child has access to the necessary powers of cognitive reasoning to correctly answer such a question.

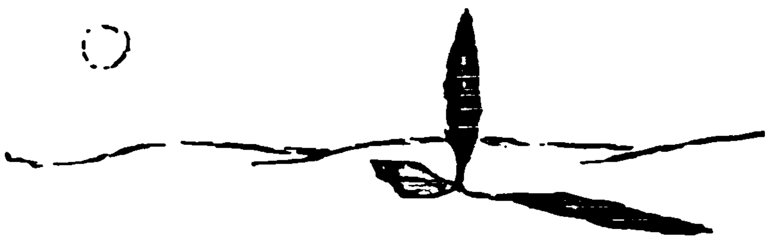


Fig 7.9.2.3 Response to question asking child (age 9) to show the position of the shadow at midday showing shortened shadow in the wrong position.

Children's responses had essentially two attributes of interest, the position of the shadow and its length and the full features of their response can be represented with a network (Fig 7.9.2.4).

The main feature of the position of the shadow was whether it was shown attached to the base of the tree or separate and unattached from it. Some children did show the shadow attached but at such a point that it could not be considered correct. The full data obtained from this question are shown in table 7.9.2.1.

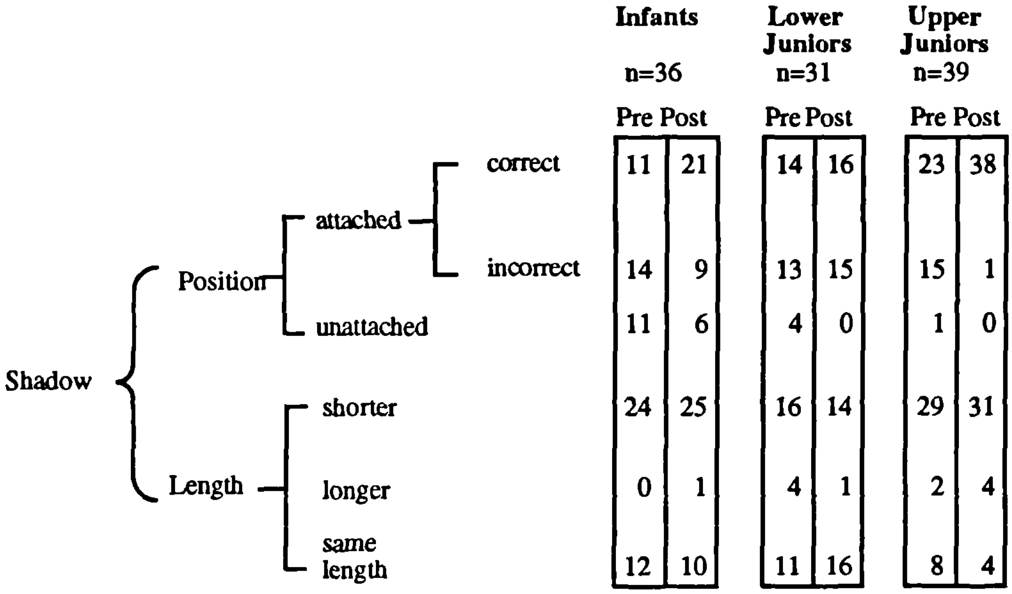


Fig 7.9.2.4: Network used for the analysis of children's responses about the length of the shadow.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Attached Correctly	31	58	45	52	59	97
Attached Incorrectly	39	25	42	48	38	3
Unattached	31	17	13	0	3	0

Table 7.9.2.1: Data for position of shadow in children's drawings to show what happened to shadow length.

What the data show is that in all cases the intervention resulted in an improvement in the number correctly answering the question and this change was significant for the infants ($p<0.05$) and the upper juniors ($p<0.01$). However, only the upper juniors after the intervention activities seem to have really understood the correct position for placing the shadow.

Table 7.9.2.2 shows the data for the length of the shadow. The data here are less conclusive. Firstly no significant changes have occurred as a consequence of the intervention and secondly, whilst infants and upper juniors were both relatively successful at showing the midday shadow as being shorter than the morning one, the performance of the lower junior group was inferior.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Shorter	67	69	52	45	74	79
Longer	0	3	13	3	5	10
Same length	33	28	35	52	21	10
Responses showing shorter shadow and attached correctly	19	42	19	22	51	74

Table 7.9.2.2: Percentage of children giving specific lengths of shadow by age groups and the percentage giving all the features of the correct response.

Some other interesting aspects of the children's understanding emerge from examining the correlations between the data. Data for children who correctly indicated that the shadow would be shorter were correlated with data for the drawing of the movement of the Sun during the day. None of these correlations was significant although it was found that in the case of the upper juniors, the correct response to the question about the shadow was a prior requirement for the correct response to the question on the daily movement of the Sun (Del =0.68, $p<0.01$). These results are somewhat surprising as it would be expected that children who knew that the Sun was higher at midday would be able to reason that the shadow would be shorter at midday. These results suggest that most children do not use the relationship between the two.

The performance of the infant group is also surprising given their weakness in predicting the correct height of the Sun at midday (Fig 7.9.1.6) and it is surmised that the explanation of their performance must lie elsewhere, possibly in the lack of a full sense of perspective and proportion which limits their ability to draw and represent reality and which results in the production of a foreshortened shadow. If this is true, then it was only the upper juniors who really show a significant understanding of what the relative shadow length should be and the intervention has done little to improve their knowledge. This would mean that the explanation of the workings of a sundial would only really be understood by the majority of children of age 10/11.

Some evidence to support this last hypothesis comes from the responses to Question 4, section B where children were asked to explain how we can use shadows to tell the time. Answers fell into those that were generally valid in that they mentioned using the shadow of the Sun; those that simply stated 'use a sundial'; a group of other responses which mentioned a wide variety of non-relevant points and those that did not answer or said they did not know. Table 7.9.2.3 shows the data obtained for this question and reveals that the number of generally correct answers was limited to a maximum of 26% for the lower juniors in the post-elicitation.

	Inf-Pre %	***Inf-Post*** %	***LJ-Pre*** %	***LJ-Post*** %	***UJ-Pre*** %	***UJ-Post*** %
Generally Valid	14	14	16	26	10	21
Don't Know	58	61	52	48	62	18
With a Sundial	3	3	3	10	18	51
Other	25	22	29	16	10	10

Table 7.9.2.3: Four categories of response of how a sundial could be used to tell the time and the percentage of children in each group giving each response.

It was only in the upper junior group, after the intervention, that a large number of responses mentioned a sundial and even then, no explanation of how it works was given. Hence the total picture presented by the data is not clear but would suggest that the explanation of the sundial may pose particular difficulty for children below the age of 10/11.

For all the groups, the following relationships were explored to see if there was any correlation between the children's reasoning.

- Children's explanations of how we can tell the time from shadows *with* correct responses to the daily movement of the Sun across the sky.

  No correlations of any significance were found for any of the groups.

- Children's explanations of how we can tell the time from shadows *with* correct responses of the height of the midday sun.

  No correlations of any significance were found for any of the groups.

• Children's explanations of how we can tell the time from shadows *with* responses indicating that midday shadows will be shortened.	A significant negative correlation (r_g = -0.35, p<0.05) was found between these two variables for the lower juniors prior to the intervention. After the intervention, the correlation was still negative but just failed to be significant. For both the upper juniors and infants prior to the intervention, and the infants post-intervention, it was found that a knowledge of a shorter shadow at midday was a precondition for a correct answer on the use of a sundial for measuring time (Del = 1, p<0.01).

Again the surprising feature of these data was the lack of any evidence of a consistent response which would demonstrate that children were operating with a coherent model relating shadow length, the principle of a sundial and the daily movement of the Sun. Instead again their knowledge would appear to consist of fragmented and different ideas bearing little relation to each other. This finding would appear to directly contradict the work of Vosniadou & Brewer (1991) who argue that their data support the view that children are operating with a consistent theoretical structure, albeit a non-scientific one.

7.10. What concept of the Earth do children have?

The 'Earth' concept, that is that we live on a sphere where 'down' is toward the Centre of the Earth, is an important idea which has to be assimilated in order to understand explanations of day and night and the seasons. It is also recognised as being a difficult idea to comprehend as a child's experience of everyday life tends to reinforce the idea that we live between two flat planes bounded by the Earth and the sky. Hence one of the purposes of the research was to examine to what extent children held a 'flat Earth' conception of the Earth or had assimilated the round Earth spherical concept.

Children's understanding was explored with three questions, the first of which showed children a selection of shapes consisting of a sphere, disc, semi-sphere, semi-circular disc and rectangle and asked them which they felt is most shaped like the Earth. The results are shown in table 7.10.1.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Sphere	69	81	81	94	92	97
Disc	28	14	10	6	8	3
Semi-circle	0	3	0	0	0	0
Semi-sphere	0	0	0	0	0	0
Rectangle	3	3	10	0	0	0

Table 7.10.1: Percentage of children choosing each type of shape when asked which one was most shaped like the Earth.

The data are interesting in showing that the conception of the Earth as a sphere was held by the majority of children from age 5 upwards and that this percentage increased steadily with age. The other predominant shape was a disc which was chosen by a diminishing percentage as children became older. It is possible that the disc represents an attempt to reconcile the experience of flatness with the picture of roundness presented in the media and elsewhere. Children were asked why they selected their chosen shape but unfortunately, this question failed to elicit a response that provided any insights into their thinking. Responses tended to be predominantly simple descriptions such as "because it's round, not flat" or "because it's round and flat" and further probing was not undertaken.A second chance to choose a shape to represent the Earth and the Sun was provided in question 1, section D where children were offered a wide variety of shapes i.e. spheres, discs, rectangles and semi-circles of two different sizes and asked to pick one to represent the Earth and one to represent the Sun. The data for these responses is given in table 7.10.2.

The data show a similar trend to that shown in Table 7.10.1 though the percentage making the scientific choice was not so high. In addition, there were clear improvements pre- and post-intervention in the number of children making such a choice and these changes were significant for the lower juniors ($p<0.05$) and upper juniors ($p<0.01$).

	Inf-Pre %	*Inf-Post %*	*LJ-Pre %*	*LJ-Post %*	*UJ-Pre %*	*UJ-Post %*
2 spheres, Sun larger	28	47	32	61	54	82
2 spheres identical size	17	14	10	3	0	8
2 spheres, Sun smaller	17	14	19	16	28	8
Sphere & Disc	22	14	39	13	15	3
2 Discs, sun larger	17	11	0	3	3	0
Disc (Sun) & Square	0	0	0	3	0	0

Table 7.10.2: Data for choices made by children of shapes to represent the Sun and the Earth (percentages).

The next question used an item from previous research which asked children to add to a drawing of the Earth to show how a ball would fall at three positions which could effectively be described as the North Pole, the Equator and Australia. A strong case has been advanced that this item reveals those children whose concept of a round Earth does not extend to the world in which they live (Nussbaum & Novick, 1976). For these children, 'down' is an absolute notion defined in terms of the horizontal planes of the earth and sky and is represented by the bottom of the page.

The essential argument for the analysis of children's responses is that those who are still clinging to the notion of a flat earth consisting of two horizontal planes, formed by the plane of the ground and the plane of the sky, have developed a commonsense notion of 'down' which is at right angles to these two planes. In this problem, these two planes are formed by the top and bottom of the page and children with this idea will show the balls falling 'down' towards the bottom of the page (Fig 7.10.1).

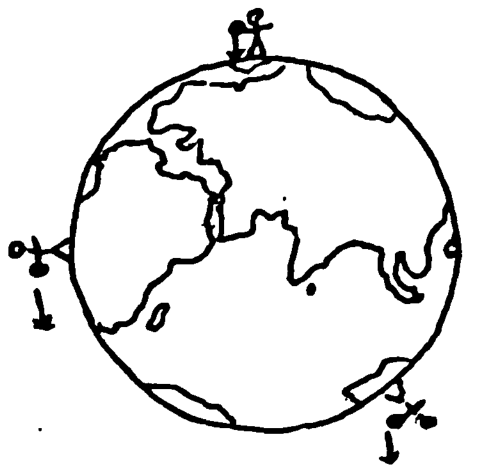


Fig 7.10.1: Response (age 8) showing non-scientific conception

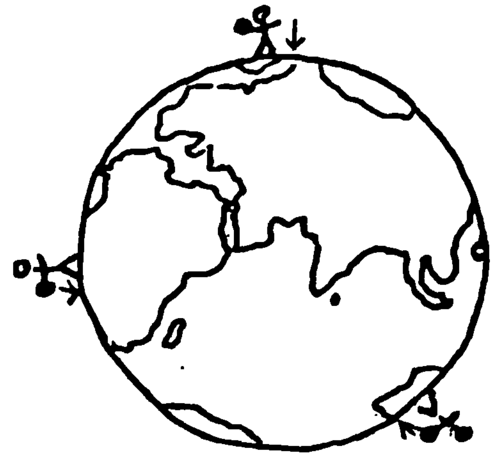


Fig 7.10.2: Response (age 10) showing scientific conception of the Earth.

The scientific conception of 'down' (Fig 7.10.2) towards the centre of the Earth is difficult to accept because children are naturally egocentric and view physical phenomena from their own perspective. To understand that people in Australia do not fall off requires a mental transformation which enables the child to see the world from other people's view. Other typical responses are shown in Fig 7.10.3 and 7.10.4.

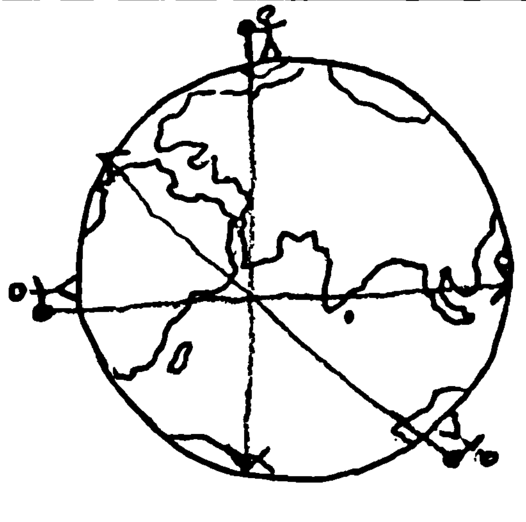


Fig 7.10.3: Response (age 7) showing ball falling radially inwards showing possible scientific conception of the Earth

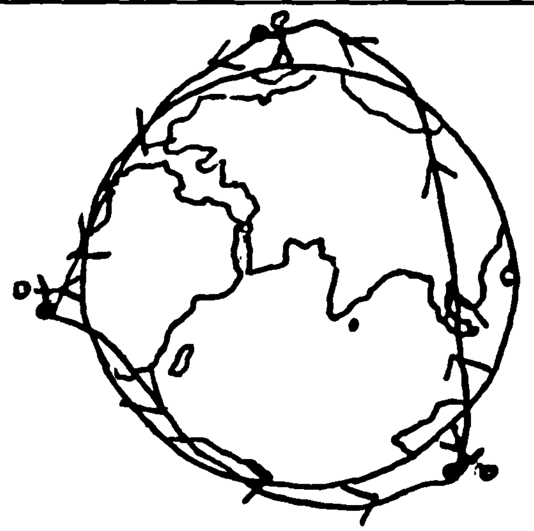


Fig 7.10.4: Response showing ball moving around the surface of the Earth lacking the scientific conception of 'down'.

Hence this item was used to explore what children's latent conceptions might be for the nature of the Earth. The data for children's responses to this item are shown in Fig 7.10.5 and the data were categorised into five groups: responses showing the ball falling vertically down; responses showing the ball emerging radially outwards; responses showing the ball falling radially inwards either to the surface or to the centre of the Earth and other responses which were not simply codeable. The latter responses tended to be ones showing the ball projected horizontally around the Earth or simply no response.

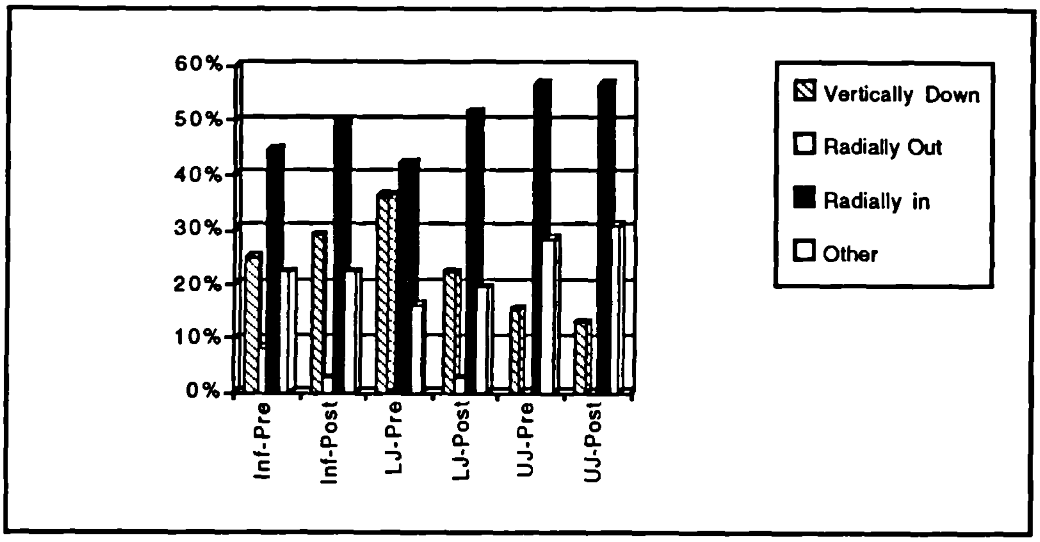


Fig 7.10.5 Chart showing percentage of each type of response by age group

The most noticeable aspect of the data was that the majority of the children show the ball falling radially in towards the centre of the Earth. This result is somewhat surprising as it contrasts strongly with the results reported by Nussbaum and Novick (1976) which would indicate that only about 20% of pupils of age 10/11 would be expected to give that response as opposed to the figure of approximately 45% obtained in this research. However, Nussbaum and Novick used more than this single item to determine children's conception of the Earth and it is possible that too much can be read into one response. Nevertheless it is an effective instrument for quickly exploring typical conceptions held by children. For instance, the responses which show the ball falling vertically down reveal that there was a significant group of children who hold the 'Flat Earth' conception.

None of the changes that occurred over the period of the intervention was found to be significant. However there was an improvement in the number of infants and lower juniors showing the ball falling radially.

The data were examined to see if there was any correlation between the shapes that children chose for the Earth and the answers they gave to the question about the direction of fall of a ball on the Earth. Answers to the latter question which showed the ball falling to the surface or to the centre of the Earth were considered to indicate a knowledge of the scientific view.

The only index of agreement between successful responses to these two items which approached significance was for the upper juniors where $r_g = 0.33$. The figures for all the other groups showed that there is little correlation between these two responses and calls into question whether children do perceive the two questions as related and deploy the same knowledge in answering the question.

7.11. What is children's knowledge of distance?

Much of the sense of wonder and fascination that comes from studying astronomy depends on a conception of size and distance. Only the individual who is able to make sense of the distances and scale of the Solar System and the Universe will begin to appreciate how small is the world on which we live. Hence this research examined the extent to which a sense of terrestrial and astronomical distances had been grasped and appreciated by children in the lower and upper juniors. This task was not undertaken with infants as the pilot had shown that such a task had little meaning for them.

Their understanding was elicited by the use of a sorting activity (Question 4, section D) which asked children to place 6 cards, each with the name of an object or town written on it, in order of the largest distance from London first. Written on the cards were Sun, New York, Moon, Mars[1], Liverpool and Southend. Children were given an opportunity to undertake the sorting activity and their results classified by whether the order was correct, whether one card was misplaced or whether their sequence was essentially incorrect showing no real awareness of the relative sizes.

	LJ-Pre %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Correct	10	29	21	33
One Item misplaced	42	26	46	38
Incorrect	48	45	33	28

Table 7.11.1: Data for children's ability to correctly sort a sequence of 6 distances by order.

In both groups of children, the intervention has improved the number who were capable of performing the task correctly though none of the changes was significant. If

1 If Mars is on the other side of the Sun to the Earth, it will in fact be further away from the Earth than the Sun. However, it was not expected that children of this age would be able to operate with such reasoning and instead would use the standard picture of the linear presentation of the planets where Mars is much nearer to the Earth than the Sun. This was also a reason for considering those responses that had just one item misplaced.

the figures for the number getting one item misplaced are collapsed with those obtaining the correct answer, then it would seem that at least half of the pupils in the 8-11 age range were capable of undertaking this task correctly or nearly so. However, this task only really provides information about whether children have established a relative scale of distance.

Hence to explore if any children had an absolute scale of distance, the next part of this question asked children to tell the interviewer how far it was to each of the places on the card. The children's responses essentially had three aspects of interest - whether they gave a number; whether the answers were very approximately correct, loosely interpreted as any figure within plus or minus 100% of the real figure; and then whether they were consistent in their use of units. The data obtained are as shown in Table 7.11.2.

	LJ-Pre %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Units given	71	35	49	59
No units	6	6	3	10
Approximately Correct	3	3	10	10
Incorrect	74	39	41	59
Don't Know	23	58	49	31

Table 7.11.2: Data for children's responses to question asking for distances to 6 specified places.

These show firstly that only a very small number of lower juniors and a slightly larger number of upper juniors were capable of providing an answer that was even very approximately correct. A much larger number of children added a unit to their answer which shows at least a linguistic familiarity with the convention for expressing distances. However, the number doing so is erratic, particularly in the case of the lower juniors where it seems to have gone down dramatically after the intervention for no apparent reason and this was the only change of significance ($p<0.01$).

What the data do show is that very few children had any sense of distance to many of these places. This would imply that any sense of scale of the Solar System may be beyond the grasp of many children.

The final part of this section was a question which attempted to find out if children had a sense of the relative size of some of the different bodies in the Solar System. This was done by providing children with six cards with the names written on (Sun, Moon, Earth, Jupiter, Mars, Saturn) and asking them to sort them by size. Responses were grouped into those that were all correct; those that were correct bar one; those that had the Sun, Earth and Moon in the correct order and those that were incorrect. The results are shown in table 7.11.3.

	LJ-Pre %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
All objects in correct sequence	0	19	33	38
All but one in correct sequence	6	6	3	10
Sun, Earth & Moon in correct sequence	23	26	3	21
Incorrect	71	48	62	31

Table 7.11.3: Data for children's responses to question asking children to sort 6 astronomical objects by size.

The data show that for both groups there was an increase in the number who got the sequence, or all bar one correct. The change for lower juniors was significant ($p<0.05$) as was the decrease in the number of upper juniors failing to give a response in the first three categories ($p<0.01$). After the intervention about 50% of lower juniors and 70% of upper juniors were capable of providing some meaningful response in that their answer fell in one of the first three categories which implied that they had some sense of scale of these bodies, and that it was possible to develop children's knowledge of this aspect of the Solar System.

The number succeeding totally, and the number succeeding with only one mistake, were collapsed to form one data item. This process was repeated for the previous sorting task and the two compared in a contingency table. This revealed that success on the task of sorting a set of cards with a range of place names on them was significantly correlated ($p<0.05$ - upper juniors, $p<0.01$ - lower juniors), after the intervention, with success on the task of sorting the set of cards for the planets, Moon and Sun for both the lower juniors ($r_g = 0.33$) and upper juniors ($r_g = 0.42$). This would suggest that such pupils have developed a sense of scale which is applied as a common criterion to both tasks. The Del coefficients indicated that success on the first task of sorting distances is a prior condition for success on the second task of sorting the Sun, Moon and Earth and planets by size. For the lower juniors, the Del coefficient was 1.0 ($p<.001$) and for the upper juniors it was 0.63 ($p<0.001$). The other Del coefficients for success on the task of sorting the planets, Moon, Sun and Earth being dependent on success in sorting the distances were not significant. This would indicate that an understanding of the relative sizes of the planets is dependent on the development in children of a basic sense of scale, size and distance.

7.12 What knowledge of astronomical bodies did children have?

The final area of interest to be explored by the research was what level of knowledge children had of astronomical bodies. Could they draw the Earth, Moon and Sun in the correct relative sizes? For instance, the English & Welsh National Curriculum expects the average 7 year old to be able to distinguish them as separate bodies. Did they know what a planet or a star was, and did they have any understanding of the sequence of the phases of the Moon? These questions were explored by the use of item 5, section B, item 3 & 4, section C and item 3, section D.

The first item simply asked children to consider that they were in a spaceship in outer space - a long way from the Earth. When they looked out of the window, they could see the Earth, Sun and Moon and the question invited them to draw what they would see. The data for the number of bodies they drew in their response is shown in Table 7.12.1.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Three bodies	92	94	90	87	92	95
Two bodies	6	3	3	6	5	3
1 Body	3	0	0	0	0	0
No response	0	3	6	6	3	3

Table 7.12.1: Percentage of children whose drawings showed one, two or three bodies.

Table 7.12.1 shows that the overwhelming number of responses to this question showed three separate bodies. In view of the formulation of this question, the results are hardly surprising. More interesting is the detail of their responses shown in Fig 7.12.1. The data collected here are for the relative sizes of the three bodies shown in the diagram.

What the data show is that the number of children who drew the Sun as being the largest body, increased for all groups as a consequence of the intervention. For both the lower and upper juniors, this change was significant ($p<0.01$) and only just failed to reach significance for the infants ($p<0.05$). These data would indicate that the concept of the Sun being a much larger astronomical body than the Earth or Moon can be assimilated by young children of all ages.

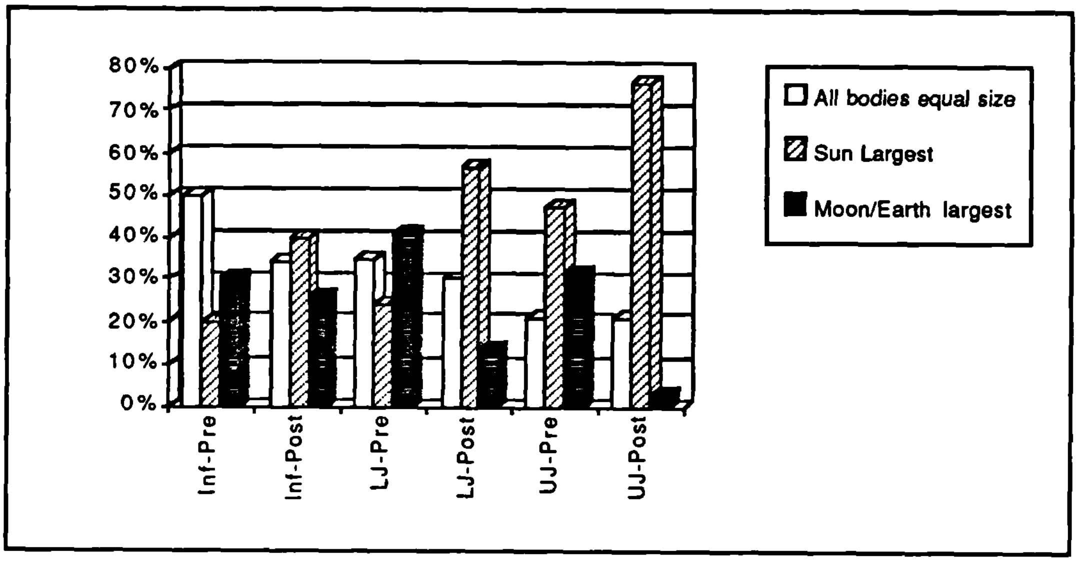


Fig 7.12.1: Data for relative sizes of bodies in children's drawings of the Sun, Moon and Earth from the window of a spaceship.

The next item asked children to indicate which out of the Earth, Moon, Sun, Venus, Mars, Polaris, Satellite, Scorpio, Alpha Centauri and Jupiter they thought were stars. Whilst some of this list of objects are not generally known, the intent behind the question was to mix objects which are commonly accepted as being stars, or associated with a star, with objects which are less familiar to see how successful children were at an item which tested a knowledge of a simple fact. This item proved difficult for many pupils and results were ultimately classified into three broad categories which were - all items correct, partially correct in that the Sun had been marked with other items, and incorrect. The results are shown in Table 7.12.2.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Correct Response	6	14	0	19	13	51
Sun and other items marked	8	14	35	48	31	31
Incorrect	86	72	65	32	56	18

Table 7.12.2: Percentage of children giving one of three categories of response to question asking them to state which objects in a given list were stars.

The data show quite clearly that this is not a task which the majority of children were able to successfully complete until they were age 10/11. The intervention has had a positive effect in all cases in improving the percentage who were able to either give a correct response or at least provide a response which was partially correct. In the case of the upper juniors this change was significant at the .01 level and at the .05 level for lower juniors. In that sense, this would imply that this simple definition of a star and its exemplars can be understood by older primary age children.

A similar question was used to explore whether children had assimilated the concept of a planet. An examination of the data found that the main categories of answer were - all planets correctly indicated, some planets correctly indicated, all planets and other objects indicated, and incorrect responses. The results are shown in table 7.12.3.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
All correct	3	6	16	26	33	62
Some planets correct	39	53	29	6	23	8
All planets correctly indicated but other objects included as well	36	36	55	58	41	31
Incorrect	22	6	0	10	3	0

Table 7.12.3: Data for children's responses to question asking them to indicate which items in a list were planets.

The data show a similar trend to the previous question. The upper juniors were the only group to show a significant increase ($p<0.05$) in the number getting the answer correct but the general trend was for an improvement in the number getting a response which was totally correct.

This trend is supported by the data obtained from a later item (Question 3, section D), asking children if they could explain what a star is. Answers were simply classified into serious responses containing relevant scientific aspects, those which were irrelevant and those for which no response was provided. The data are shown in Fig 7.12.3 and show a similar improvement in children's response with age.

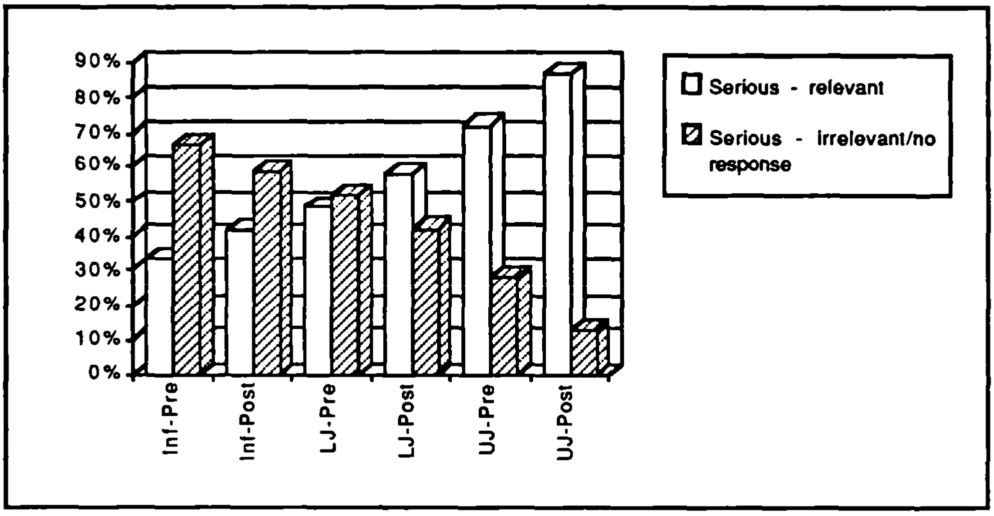


Fig 7.12.3 Chart showing the data for children's explanations of a star.

The second part of this question asked children to tell the interviewer the name of a star and the data for their responses are shown in Table 7.12.4.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Sun	0	8	16	35	31	56
Other incorrect response	36	33	42	39	31	28
Don't Know	64	58	42	26	38	15

Table 7.12.4: Data for children's responses when asked to provide the name of a star.

The data show that a steady improvement across all age ranges in the number of children who were able to say spontaneously that the Sun was a star. Perhaps not surprisingly, no child gave any other correct response to this question since the names of stars are not generally well-known. The data also show that the number of correct answers increased after the intervention and that the change for the upper juniors was significant ($p<0.05$).

The final question explored whether these children were aware of the different phases of the Moon that can be observed in one month and whether they could place them in the correct sequence. A drawing of the different phases of the Moon was shown to children and they were asked to mark which of these they had previously seen. The data for their responses are shown in Figs 7.12.4a & 7.12.4b. They were then asked which order they thought that they appeared in.

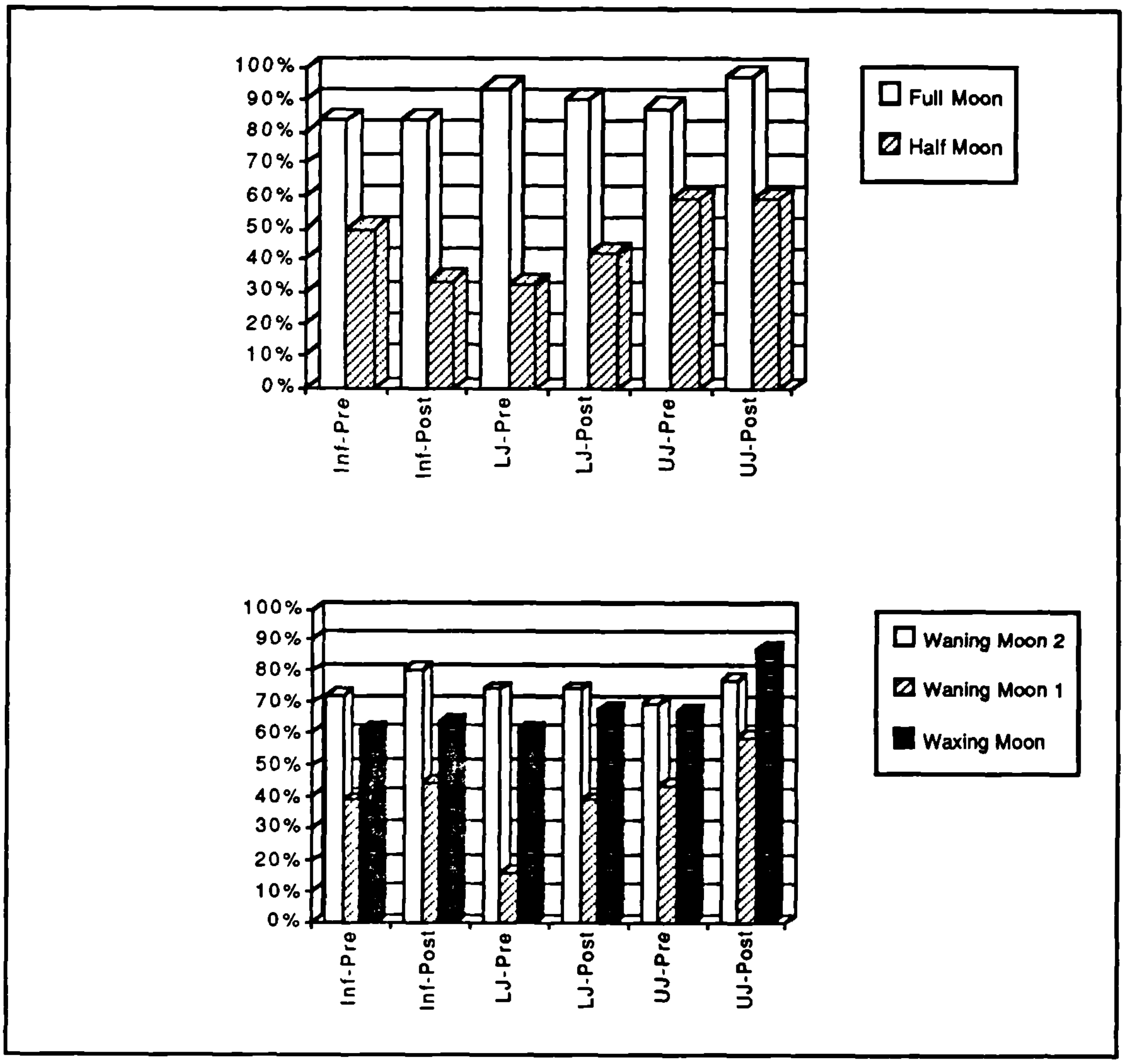


Fig 7.12.4a & 7.12.4b: Chart showing which phases of moon children recognised (percentages)

Not surprisingly a Full Moon was recognised by the greatest percentage of children at all age levels and three phases of the Moon were recognised by more than 50% of all children. Interestingly, there seemed to be little variation across the age groups and this would suggest that most children had experienced some observation of the Moon at a relatively early age.

However the data in Table 7.12.5 show that only a small minority of lower and upper juniors were capable of ordering the phases of the Moon correctly. A larger number could provide a response which was partially correct in that only one item was incorrectly placed. The lack of a correct sequence is most likely indicative of a lack of any model of the cause of the phases of the Moon which enables a correct sequence to be generated. On first sight, the intervention seems to have had little effect on children's capability to answer the question correctly. However, if the correct responses are collapsed with those which show a partially correct order, then for both the lower and upper juniors there was a significant improvement ($p<0.05$) in their knowledge of the sequence of the phases of the Moon.

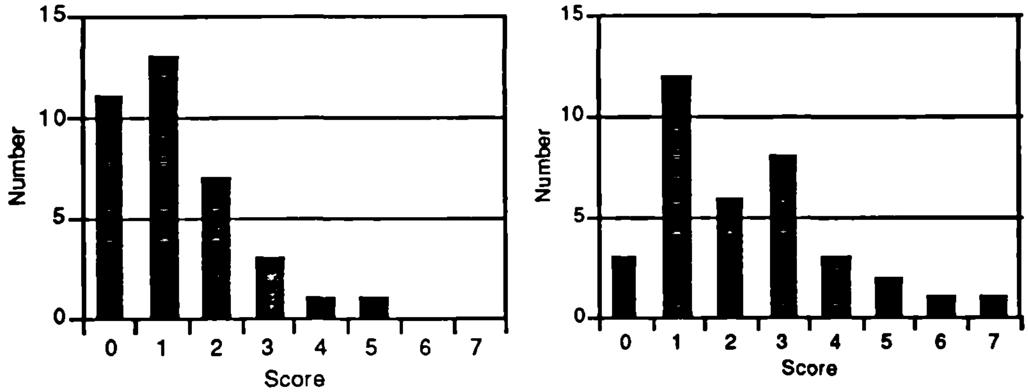
	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Correct Order	0	0	6	10	0	10
Part Correct Order	3	11	23	32	26	26
Incorrect	19	31	71	58	72	64
No Response/ Don't Know	78	58	0	0	3	0

Table 7.12.5: Data for children's responses for the sequence of the phases of the Moon.

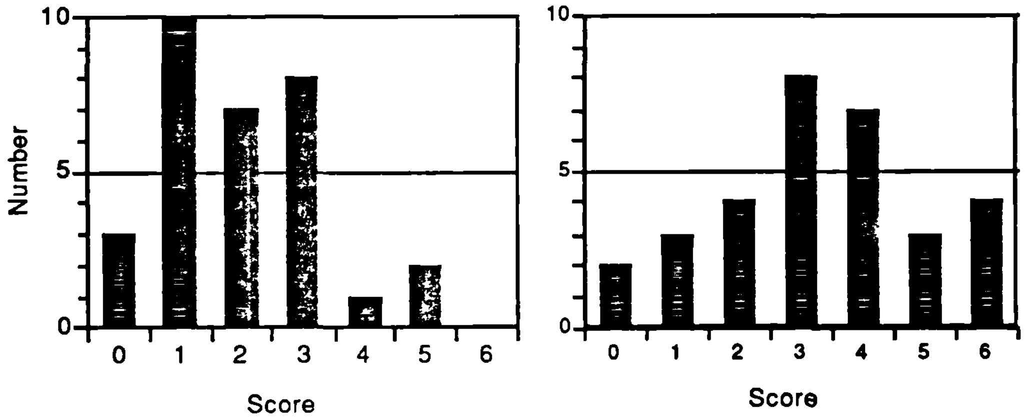
For all groups a variable which represented their astronomical knowledge was constructed[2] from their responses to the questions about the sequence of the phases of the moon, their drawings of the Sun, Moon and Earth, their knowledge of which objects are stars and their knowledge of which objects are planets. The distributions for the scores are shown in Figs 7.12.5, Fig. 7.12.6 & Fig 7.12.7

2 This was constructed from their responses to -
- Question 5, section B where a correct response was given double the weighting of an incorrect response;
- Question 3, section C;
- Question 4 (a), section C where a totally correct response was given double the weighting of a partially correct response;
- Question 4 (b), section C where a totally correct response was given double the weighting of a partially correct response.

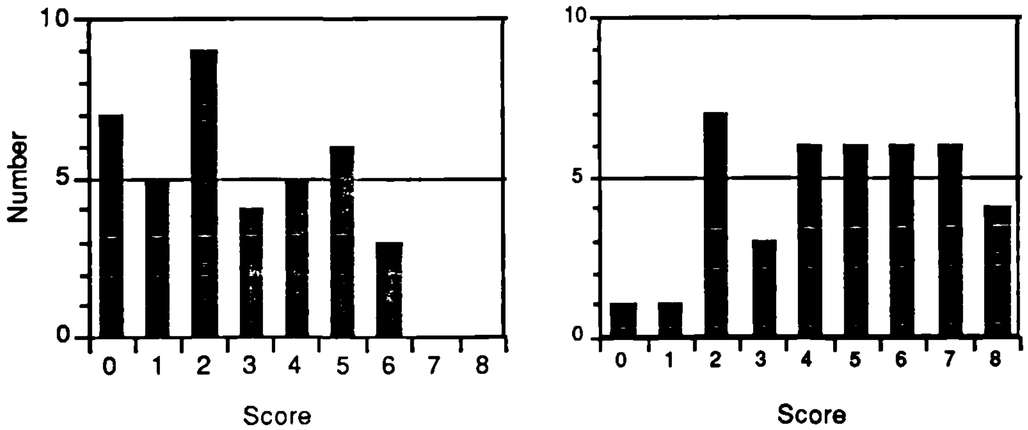
There was clearly an improvement in their general level of knowledge after the intervention for all groups and a paired t-test shows that the difference was highly significant ($p<0.01$).



Infants-pre Fig 7.12.5 Infants-post



Lower juniors-pre Fig 7.12.6 Lower juniors-post



Upper juniors-pre Fig 7.12.7 Upper juniors-post

Fig 7.12.5, Fig. 7.12.6 & Fig 7.12.7: Bar Charts showing range of scores by grouping on questions eliciting astronomical knowledge.

7.13. Children's understanding of scientific models and their general use

The final section of this research looked at the issue of how children understanding and knowledge of the scientific model for the explanation of day and night was related to the Copernican view of the movement of the Earth around the Sun. Table 7.13.1 shows the percentage of children who in their responses to Question 1, section D showed the Earth spun on its axis once a day and, who also showed that in one year, the Earth goes around the Sun once.

	Inf-Pre %	*Inf-Post* %	*LJ-Pre* %	*LJ-Post* %	*UJ-Pre* %	*UJ-Post* %
Scientific explanation of Day and Night	8.3	5.6	9.7	19.4	35.9	46.2
Full Copernican explanation of movement of Sun and Earth	8.3	6.0	0.0	25.8	44.0	69.2

Table 7.13.1: Percentage of children in each age group who held the scientific explanation of day and night and the annual movement of the Earth

These data show that only a substantial number of the upper juniors had assimilated these models and used them in their responses. For this group, it is interesting to see to what extent it is the same children who hold these models before and after the intervention. Table 7.13.2 shows simple cross-tabulations of the data.

Post Elicitation	*Pre-Elicitation* Incorrect	*Pre-Elicitation* Correct
Incorrect	19	2
Correct	6	12

Table 7.13.2a Scientific Explanation of Day and Night

Post Elicitation	*Pre-Elicitation* Incorrect	*Pre-Elicitation* Correct
Incorrect	11	1
Correct	11	16

Table 7.13.2b: Copernican Explanation of Annual Movement of the Earth

Tables showing cross-tabulation of responses pre and post for models held by upper juniors

These tables show that for both models, there is a reasonable minority who consistently use the scientific model for their responses in both the pre-elicitation and the post-elicitation. This would suggest that once the model has been internalised and assimilated, it is relatively robust and unchangeable. Such an analysis is supported by the Del values: the value for success in providing the scientific explanation in the post-elicitation being dependent on success in providing the scientific explanation in the pre-elicitation was 0.73 and highly significant ($p<0.001$). The G index of agreement was + 0.59 and similarly significant. The G index of agreement for the responses to the question eliciting the Copernican model was +0.38 ($p<0.01$) and the Del value for the interdependence of the responses was 0.81 ($p<0.001$) showing that success in the post-elicitation was highly dependent on success in the pre-elicitation.

Table 7.13.3a & 7.13.3b respectively show how many of the children who held the correct/incorrect scientific explanation for day and night, also held the correct/incorrect scientific explanation for the annual movement of the Earth in the pre- and post-elicitation respectively.

Again, these tables show that there is a clear correlation between the children who have assimilated the scientific explanation of day and night and those who have assimilated the scientific explanation for the annual movements of the Earth. The G index of agreement was 0.64 prior to the intervention and 0.44 after the intervention. Both were highly significant ($p<0.01$). The Del values (0.75 pre-elicitation, 0.82 post-elicitation) also show that the development of the scientific model for day and night is dependent on success in assimilating the Copernican world view rather than the inverse.

	Scientific Explanation for Day & Night	
Copernican Explanation	Incorrect	Correct
Incorrect	20	2
Correct	5	12

Table 7.13.3a: Pre-Elicitation

	Scientific Explanation for Day & Night	
Copernican Explanation	Incorrect	Correct
Incorrect	11	1
Correct	10	17

Table 7.13.3b: Post-Elicitation

Tables showing cross-tabulation between responses for the daily and annual movements of the Sun and Earth.

Further cross-tabulations were used to explore to what extent pupils' abilities to explain the daily movement of the Sun was related to the scientific explanation for the occurence of day and night (Table 7.13.4a & 7.13.4b) and also, the correlation between the scientific conception of 'down' and the scientific model of the the occurrence of day and night (Table 7.13.5a & 7.13.5b). Since so few infants and lower juniors had successfully assimilated this model, the data have little meaning as some cells have frequencies of 0, 1 or 2 which limits any inferences which can be drawn from the statistics. Hence the data discussed here are limited to the results for upper juniors.

Scientific Explanation for Day & Night		*PRE* Daily Movement of the Sun: Incorrect	*PRE* Correct	*POST* Incorrect	*POST* Correct
	Incorrect	24	1	18	9
	Correct	11	3	3	9

Table 7.13.4a **Table 7.13.4b**
Cross-tabulation of responses by Upper Juniors for their explanations of the daily movement of the Sun and their explanation of day and night.

The G index for the relationship between the scientific model of the daily movement of the Earth and the apparent motion of the Sun were both significant in the pre- and post-elicitation ($p<0.01$). Analysis of the Del coefficients shows that the significant relationship was in the post-elicitation where knowledge of the daily movement of the Sun seemed to be a pre-condition for success in providing the scientific explanation for the occurrence of day and night (Del =0.54, $p<0.01$).

Scientific Explanation for Day & Night		*PRE* Scientific Concept of the Earth: Incorrect	*PRE* Correct	*POST* Incorrect	*POST* Correct
	Incorrect	15	0	11	10
	Correct	2	12	6	12

Table 7.13.5a **Table 7.13.5b**
Cross-tabulation of responses by Upper Juniors for their conception of the Earth and their explanation of day and night.

Analysis of the figures shown in Table 7.13.5a and 7.13.5b shows that the significant relationship was in the pre-elicitation. The G index of agreement was 0.86 which is significant at $p<0.01$. Similarly the Del coefficients show that understanding the scientific concept of the Earth and the scientific explanation for day and night are both highly dependent on each other (Del = 0.67, 1 $p<0.001$ for both) and these two items seem to be strongly associated. However after the intervention, there was no such association. A possible explanation is that the intervention has been more successful in developing the scientific concept of the Earth than it was in improving children's understanding of why day and night happens which has resulted in a weakening of the pre-existing association.

Cross tabulations were also conducted with the data for the relationship between the Copernican world view and responses for the daily movement of the Sun and children's conception of the Earth but no relationships of any significance were found. The implication of these results is that there is some evidence that, prior to the intervention, the scientific explanation of day and night is dependent on an understanding of the annual movement of the Earth and the scientific conception of the Earth. After the intervention, whilst this understanding was still dependent on a knowledge of the annual movement of the Sun, it was now contingent on a knowledge of the daily trajectory of the Sun across the sky as well.

The implication of this data is that the development of the Copernican world view is a central concept for developing many of the other aspects of the scientific world view in this domain. The data in section 7.7 would appear to show that the development of the Copernican world view appears to have happened for these children in a holistic matter. There were very few children who had assimilated separately the information or idea that the Earth moves or that it moves around the Sun once. Children either understood and articulated both of these pieces of information in their response or neither.

Finally there were no significant G indexes of agreement between children's choices for the shape of the Earth and their responses which indicated that they had understood the scientific concept of the Earth, i.e. that objects fall towards the centre regardless of where they are. These results would support the argument that these two ideas are seen by children as being unrelated, and that in choosing a shape for the Earth, they do not necessarily conceive of it as the ground on which they live.

8. *Whither Constructivism? - a discussion of the implication and meaning of this research and its results.*

' The key factor in the evolution of science remains, nevertheless, the power of the human mind to recognise a comprehensible pattern in a mass of detail.'

(Ziman, 1979), p 150

8.1. Introduction

Ziman's comment is as relevant to the study of science education as it is to science and the search for a recognisable pattern remains a core commitment of any inquiry. What we ask of research is a body of knowledge and a guide to action that is significantly more reliable than inductive generalisations born of everyday experience and intuition Thus, this thesis began with an attempt to address two research questions:-

- What ideas about particular science concept areas do young children, age 5-11, hold prior to instruction?
- What conceptual change can be achieved through the use of intervention activities that provide opportunities to elicit children's thinking prior to instruction, that attempt to challenge children's thinking and which place more emphasis on the active construction of meaning?

Chapters 4, 5, 6 and 7 have been an attempt to provide a descriptive answer to the first question. The second question has a two dimensional answer - at one level, there is the task of summarising and comparing the changes, and lack of changes, that have been achieved by this work. Therefore this chapter initially considers what picture is portrayed by the data obtained from this study to show that this approach has achieved limited success and that some of the current statements of attainment in the National Curriculum are unrealistic. A further exploration of the data is also provided to investigate a more demanding epistemological question - how is it that the young child comes to know and understand science? With this question in mind, the possible contributions of constructivism, genetic epistemology, commonsense realism and the role of language and metaphor are explored to argue that it is the latter which provides the most useful avenue for further exploration of the growth of a child's knowledge and understanding.

Finally, as a contribution to the notion of a meta-research agenda and to be 'critically self-reflective' (Robottom and Hart, 1993), it will be argued that there are a number of methodological and epistemological problems with constructivism that have emerged during the conduct of the study that need to be recognised by future research. Coupled with no one, self-evident pattern in the data, but instead evidence for a number of influences on children's learning, the only tenable position for science education is one which recognises heterogeneity with the necessity for considerably more emphasis to be given to the development of linguistic competency in the domain of science.

8.2. Changes achieved by the intervention

The simplest method for formulating an answer to the previous question is to list all the significant changes in children's understanding that have occurred in each area of investigation. Table 8.2.1 summarises these for the intervention conducted for children's understanding of light.

The table shows that for the lower juniors there have been 6 positive changes, three at the .05 level and three at the .01 level. For the upper juniors, there have been 12 changes in all, nine positive and three negative. Thus more changes have occurred for the upper juniors though not all of them were positive. The table also shows that some aspects of the children's knowledge did not change because the feature was already well assimilated. The other aspect of the change revealed by Fig 4.12.2.1, Fig 4.12.2.2, Fig 4.12.3.1 and Fig 4.12.3.2, is the dynamic nature of the changes that have occurred which is masked by the simple counts for the networks. Children's understanding is regressing as well as progressing but the overall picture is positive.

Examined from the perspective of the defined learning goals (section 4.3.2), the achievements are more limited. However, the intervention has succeeded in improving children's representations of light, the notion that it travels in straight lines and their models and explanations for vision. The limited achievement of these aims, can be partly explained by the recognition that the learning goals were only one factor driving the formulation of the intervention. More significant is that even within these improvements, very few represent a movement to the scientific understanding. The implication from this research is that progression in understanding is a series of steps, a journey along a dimly lit road with many stages on the way. The research has identified some of these stages for young children but unfortunately, there would appear to be no singular path through these. Also with certain aspects of knowledge, the data would appear to show that there is regression in children's understanding which is characteristic of U shaped growth of understanding (Karmiloff-Smith, 1974; Strauss, 1978). Thus it would appear that the research has le some children, in some contexts, to recognise that both the eye and light are involved in explaining vision, but as yet they have been unable to generate a consistent, generalised model and instead, are operating with inconsistent models so that their understanding appears to have regressed. For some children this may be the path by which scientific understanding is achieved.

Item	Table No	Lower Juniors	Upper Juniors
Bulb shown as sources of light	4.7.2	*	*
Fewer descriptions of secondary sources			(*)
Light arrives by shining		*[1]	
Using lines as a means of representing light	4.8.1	**	**
Using beams to represent light	4.8.2		**
Use of more than one means of representing light			(**)
Knowledge of primary sources of light	4.8.3	†[2]	†
Using extensive lines to represent light	4.9.1		†
Representing light with short lines around sources.	4.9.4	†	†
Use of link between eye and object to explain vision	4.9.6.1	**	**
Use of object/eye and source/eye links to explain vision			**
Single consistent model to explain vision (not necessarily correct)	4.9.6.1	**	
Dual inconsistent model to explain vision			(**)
Reduction in explanations with no links			*
Reduction in No. providing no explanation		*	*
Reduction in use of active vision i.e. light to object from eye			**
Light shown going to eye from object			*

Table 8.2.1. Summary of all the significant changes for young children's understanding of light.

[1] In this table and the others that follow, a single asterisk indicates a change significant at the .05 level, a double asterisk - one significant at the .01 level and any changes that are considered to be a move towards an understanding further from the scientific view are contained in brackets, e.g. (*).

[2] This symbol is used to indicate that these ideas were well understood by the majority of the sample in the pre-test and therefore no significant changes were obtained in the children's understanding.

This research was begun prior to the introduction of the National Curriculum (DES, 1989; DES, 1991) and the learning goals that were used and explored in the research are only partially matched at level 5 where the requirement is that children should 'understand how the reflection of light enables objects to be seen.' Since only 8 out of 33 upper junior children after the intervention gave the scientific explanation for vision, this would imply that such understanding is only achievable by the more able child at age 11 which is consistent with the expectations defined by the Task Group on Assessment and Testing (Black, 1987).

A similar analysis for the intervention work on electricity gives the following picture.

Item	Table/Fig No	Infants	Lower Juniors	Upper Juniors
More descriptive statements about electricity	Fig 5.7.1	**		
Association of electricity with warmth			*	
Electricity needed for living				**
More scientific ideas of how electricity is produced.				*
Improved idea of speed of travel		**		
Improved idea of functional connections for a circuit	5.8.1 5.8.2 5.8.3	**		**
Improved understanding of which materials are conductors	5.9.4	**		†
Improved explanation of how to test for conductors	5.9.5	*		

Table 8.2.2. Summary of all the significant changes for young children's understanding of electricity.

Again the data show where there have been some successes in moving children's understanding towards that of the scientist. This time, there have been more significant changes in the understanding of infants with the least impact with lower juniors. Some doubt must be cast on the latter result though, because of the small sample size (n=18). Viewed from the perspective of the learning goals, significant improvements have been made in their understanding of the functional connections in an electric circuit and which materials conduct electricity. The lack of change in the upper juniors' understanding of which materials do/do not conduct is accounted for by the fact that they appeared to have a good comprehension of this concept prior to the intervention. However, there has been only a limited change to upper junior children's understanding of how electricity is produced and no development of a concept of an electrical pushing force with any group, i.e. voltage.

Again, this phase of the research was conducted prior to the publication of the National Curriculum and the only learning goal this research and the National Curriculum share is the level 3 statement that pupils 'should know that a complete circuit is needed for electrical devices to work.' The data in table 5.8.1, 5.8.2 and 5.8.3 obtained for children's responses on how to connect a bulb to a battery, would indicate that less than 50% would possibly attain this level prior to the teaching process conducted in this research. After the intervention, a majority of both lower and upper juniors were capable of demonstrating this knowledge. Given that level 3 represents the achievement of a top infant or a below average upper junior, this data would appear to suggest that this criterion is set, at least approximately, at the correct level. However, some doubt is cast on this result by the data from Table 5.9.5 for children's ability to construct a circuit to test whether a material will conduct. Here only 24% of upper juniors after the intervention were successful. Thus the data show that the success of children on this target is critically dependent on the context in which the problem is set.

Turning to the processes of life, the changes obtained are summarised in table 8.2.3. In this phase of the research all the significant changes have been positive. Other positive changes not shown are the increase by both infant and lower juniors in the number of parts of the body shown in their drawings (Table 6.8.4). Marginally more changes seem to have occurred for the infants.

The learning goals for this section were defined in terms of the National Curriculum (section 6.4). Since the commencement of this research, the National Curriculum for science has been amended (DES, 1991). The new science order expects that pupils should develop knowledge and understanding of 'life processes and the organisation of living things' and that children's progress should be measured by the following statements of attainment (Table 8.2.4). What are the *implications of this approach* for the achievement of these aims?

Item	Table/Fig No	Infants	Lower Juniors	Upper Juniors
Better understanding of which foods are 'healthy'.	6.7.2			*
Increased awareness of the role of exercise as a means of keeping healthy	6.7.5		*	
Understanding of what food constitutes 'a healthy meal'.	6.7.6		†	†
Muscles found everywhere in the body	6.8.1	*		
Improved understanding of the shape of the heart	6.8.2			*
Recognition that heart pumps blood around the body	Fig 6.9.2.1		**	
Fewer statements that the purpose of the heart is to keep you alive.				*
Connection between mouth and stomach shown	Fig 6.9.9	**		
Continuation of digestive tract beyond stomach shown		**		
Knowledge that solids and liquids are both digested in one location			†	†
Reduction in use of external features to distinguish living from non-living objects	Table 6.10.4	**		
More use of behavioural features to discriminate living from non-living		**	**	
Reduction in use of 'actions' to discriminate living from non-living objects				**
Knowledge of names of parts of a plant			†	†

Table 8.2.3. Summary of all the significant changes for young children's understanding of the processes of life.

Since the original levels of attainment did not have the current level 1 requirement for children to name the external parts of the body, this aspect of their knowledge was not explored. As for the second component of the level 1 target about flowers, the data in table 6.11.1 would suggest that at least 80% of lower and upper juniors would have little difficulty in achieving this target. However only 40% of infant children were able to appropriately mark the stem when asked, and the intervention did little to significantly improve the children's pre-existing knowledge.

Level 1	(a) be able to name the external parts of the human body and a flowering plant.
Level 2	(a) know that plants and animals need certain conditions to sustain life.
Level 3	(a) know the basic life processes common to humans and other living things.
Level 4	(a) be able to name and locate the major organs of the human body and the flowering plant.
Level 5	(a) be able to name and outline the functions of the organs and organ systems in mammals involved in circulation and reproduction and those in flowering plants involved in sexual reproduction.

Table 8.2.4: Statements of attainment for 'Processes of Life' (DES, 1991)

The level 2 statement expects pupils to know the conditions necessary to sustain life and was not present in the statements of attainment as originally formulated (Table 6.4.1). Therefore, these issues were not specifically explored in the elicitation. The next statement essentially expects children to be able to identify the basic processes of life and to recognise that these are common to themselves and familiar animals. The data gathered here would suggest that only a minority of children are likely to attain such a level of knowledge and understanding. Whilst movement and growth are the most commonly recognised processes of life, these criteria were only used at best by 46% of upper juniors in deciding whether an object was living, once living, or never alive. Variations in the questions, such as that used by Lucas et al (1979), where the child was shown a photograph of a indeterminate object and asked to explain how they would tell if it was alive produced little better in the way of understanding. They found that only a maximum of 26% of primary age children mention 'breathing' as a criterion for deciding. Consequently these data would suggest that such a level of attainment is too high an expectation of a top infant and unlikely to be achieved by even the average upper junior.

The level 4 statement expects children to be able to 'name and point to the approximate positions of organs such as heart, lungs, stomach and kidneys in humans, and stamens and ovary in a flowering plant.' The data in table 8.2.5 gives the maximum percentage of children in each age group who identified each of these organs in their drawings and gives some insight into whether such an expectation is reasonable.

Organ	*Infants* %	*Lower Juniors* %	*Upper Juniors* %
Heart	69	87	78
Lungs	26	39	67
Stomach	65	30	60
Kidneys	3	13	43

Table 8.2.5: Maximum percentage of children who indicated each organ in their drawings

Assuming that the figure for the number of lower juniors indicating the stomach was an aberration, this attainment target would look to be achievable by the majority of children as long as questions are restricted to basic organs and do not attempt to elicit where such organs as the kidneys and liver are located. If so, the likely chance of children achieving such a level of attainment would diminish substantially.

Only data for children's ability to locate the heart were collected. A maximum of 48% of infants, 22% of lower juniors and 9% of upper juniors correctly indicated the position of this organ. Although this is an organ where knowledge of its location and shape is particularly susceptible to misconceptions, these data would suggest that many children would again experience difficulties in attaining such a level of attainment which, by definition is the average level of attainment for an 11 year old. No data were collected for children's knowledge of the organs and parts of plants.

The final attainment target expects a knowledge of organs and their function in mammals and plants, though it is restricted to the reproductive organs for plants. Such a level of attainment is to be achieved by able, top juniors and the data in Fig 6.8.1 show that a maximum of 74% indicated that the heart 'pumps blood'. However, this does not show that they understood that there is a double pattern of flow (systemic and pulmonary). The question used here failed to explore the models of the circulation system held by pupils, but the work of Mintzes et al (1991) suggests that many children do not hold closed circulatory models which may be implicit in this attainment target. Children's knowledge of the organs of plants and their function was not explored.

The conclusion that can be drawn here is that attaining this level of knowledge and understanding was not a simple matter for many children, and that in particular, the knowledge associated with level 4, or even level 3, was not commonly held at the age of 11 at which they will be tested. Such comments are based solely on the data reported here. Thus it is not contended that such levels of attainment are simply not achievable, but that *within the context of this approach*, these data indicate that such levels of attainment are unlikely to be achieved.

The picture is completed by examining the significant changes in children's understanding achieved by the final intervention in the areas of astronomy. This explored the development of their ideas and theories about astronomical phenomena and a summary of the changes is presented in Table 8.2.6a and its continuation, Table 8.2.6b.

Item	Table/Fig No	Infants	Lower Juniors	Upper Juniors
Knowledge of how long a day is	Table 7.6.1		†	†
Knowledge of length of a month	Fig 7.6.3			†
Knowledge of length of a year	Table 7.6.4			†
Improved knowledge of year length			*	
General concept of time and its units	Page 234		*	
Knowledge of temperature difference between summer and winter		†	†	†
Knowledge of vertical displacement of Sun between winter and summer	Table 7.8.1			**
Development of a model of the annual movement of the Earth/Sun system	Fig 7.8.4		**	
Earth goes round the Sun	7.8.6		**	
More aspects of the scientific explanation of the annual movement of the Sun/Earth	Table 7.8.3		**	**
Scientific explanation for the occurrence of day and night	Fig 7.9.1b			**
Physical (as opposed to personal) explanation for the occurrence of day and night	Table 7.9.1		*	*

Table 8.2.6 a. Summary of all the significant changes for young children's understanding of the Earth in Space- part I

The large number of positive and significant changes definitely provide a convincing case that the pedagogy used here can achieve effective change. The very distinctive pattern that emerges from this analysis is twofold - firstly that the overwhelming majority of such changes in this domain have been for the lower and upper juniors.

Secondly, it would appear that more changes have occurred in this topic. Such an interpretation based on the quantity of changes is inevitably simplistic as it takes no account of the difficulty of the ideas and cannot be used as a method of judging the effectiveness of the intervention. Instead, these data provide evidence of the kinds of developments in children's understanding that can be achieved in children's astronomical understanding if this approach is used.

Item	Table/Fig No	Infants	Lower Juniors	Upper Juniors
Explanation for day and night - only one body moves	Fig 7.9.2		*	
Explanation for day and night - Earth moves	Fig 7.9.3		**	**
Knowledge of shape of the Earth	Tab 7.10.1	†	†	†
Knowledge of the daily movement of the Sun	Tab 7.10.1.1			*
Understanding of the relationship between Sun, object and shadow	7.10.2.1		*	**
Correct choice of shapes for the Earth	7.11.2		*	**
Use of units for distance measurements	7.12.2		(**)	
Placing planets in the correct sequence	7.12.3		*	
Draw Sun as the largest body in the Solar System	7.13.1		**	**
Know that Sun is a star	7.13.2		*	**
Knowledge of phases of the Moon	7.13.5		*	*
General astronomical knowledge	Fig 7.13.5 7.13.6 7.13.7	**	**	**

Table 8.2.6 b. Summary of all the significant changes for young children's understanding of the Earth in Space- part II

Moreover, the first result *is* important as it shows clearly that the approach taken by the intervention has a much more positive result if used with upper juniors. It inevitably begs the question whether the theory-based and abstracted nature of knowledge in astronomy is only accessible to older children. Notably the only significant change that has occurred for infant children is in their astronomical knowledge which is essentially of a propositional nature, e.g. which objects are planets, the phases of the Moon and knowledge that the Sun is a star.

How effective has the intervention been in achieving its learning goals? Again, these were based on the levels of attainment in the National Curriculum which are a set of statements of expectation formulated by an empirical process using the professional judgements of a body of science educators. Yet there is little research that has been undertaken in this domain that would support or confirm their judgements. The revised version of the attainment targets (DES, 1991) is shown in Table 8.2.7.

Level	New Attainment Target
	Pupils should:
1	• be able to describe the apparent motion of the Sun across the sky.
2	• know that the Earth, Moon and Sun are separate spherical bodies
3	• know that the appearance of the Moon and the altitude of the Sun change in a regular and predictable manner
4	• be able to explain day and night, day length and year length in terms of the movement of the Earth around the Sun
5	• be able to describe the motion of the planets in the solar system

Table 8.2.7. Levels of Attainment in the current National Curriculum (DES, 1991)

Clearly the level 1 requirement that children should be able to describe the apparent motion of the Sun across the sky is only achievable by a *maximum* of 31% of upper juniors after the intervention. Whilst there is nothing intrinsically difficult about this piece of knowledge, as it is a concrete observable fact, it does show that the majority of children were not aware of the Sun's trajectory across the horizon, and that more activities than those undertaken in this intervention are required to achieve change. Even then, the data reported in this study question whether the idea is easily assimilated and suggest that it will only be acquired as an isolated fact. However, table 8.2.6b does show that a significant improvement in the understanding of this piece of knowledge was achieved for upper juniors.

Changes that have contributed to a more effective understanding of level 2 are the improved facility to recognise the Sun as the largest body (upper and lower juniors) and the enhanced awareness that the Sun is a star (upper and lower juniors). In addition, the intervention enhanced the general astronomical knowledge for all three groups.

The data show significant changes for both upper and lower juniors in their knowledge of the phases of the Moon and for the daily and seasonal movements of the position of the Sun. Such changes would be important for acquiring the knowledge necessary to attain level 3. Table 8.2.6a and 8.2.6b also show that the intervention has significantly improved many of the models and explanations that children offer for day and night and the annual movement of the Sun - understanding necessary to attain level 4.

Finally, the level 5 statement requires children to be able to describe the motion of the planets in the solar system. Since this attainment target was introduced to the second version of the National Curriculum, after the research had begun, this aspect of children's knowledge was not specifically addressed and no changes of note have occurred which would help children meet this requirement.

Overall, even though the research was not conducted as a controlled experiment - what conclusions can be drawn? In that it was an attempt to study a social situation with a view to improving the quality of action within it (Winter, 1989), the major effect of this intervention *was positive*. Table 8.2.8 shows a summary of the number of changes that have been achieved that were significant at the .05 level or less.

Group	*Light*	*Electricity*	*Processes of Life*	*Earth in Space*	*Total*
Upper Juniors	12	3	4	12	31
Lower Juniors	6	1	3	16	26
Infants	-	5	5	1	11

Table 8.2.8: Total number of changes which were significant at .05 or less

The one clear point that emerges from this comparison is that the intervention was notably more successful with upper and lower juniors than it was with infants. There are two possiblities that might explain this result. The learning goals could have been inappropriate for infants and there is clear evidence from the data collected for the study of the Earth in Space that this may be so. Secondly, the nature of the intervention strategies with an emphasis on discussion and group work again may have been inappropriate for the limited social and linguistic skills of infant children. Only further research would resolve the question exposed by these results.

Ultimately, the question of whether this is a better or inferior method to others must be left for the reader to judge from a reading of the context and approach. The process was collaborative and participatory and the work reported here is offered both as a model for teachers confronted by the problematic of teaching primary science, and as a test of an educational practice within a context that is identifiable to teachers (Shymanky & Kyle, 1992). As such, this research must be seen as a contribution to the intersubjective consensus of what contributes a valid pedagogy. Attempts to tightly control the strategies adopted by the teachers and the events that have occurred in these interventions over a substantial period of time are inevitably doomed to failure, given the wide number of variables to be accounted for. Thus, even if a more experimental approach were to be adopted, the external validity of the result would be open to question as much as, if not more than the internal validity of the results, and it is argued that the type of approach adopted here is essential if the results are to have value for the wider community of practising teachers.

So far this thesis has undertaken two tasks, an empirical description of children's thinking and a demonstration that a pedagogy which bases itself in a process of starting from children's understanding to negotiate new meanings can be effective. However, the meta-research question inherent in the data is the search for patterns that would simplify and provide coherence enabling a deeper understanding of the possible origins of the child's ontology. What patterns do the data point to?

8.3. The effect of context - or do children have unified theory-like structures?.

What is the nature and structure of children's scientific knowledge? Is there any evidence for coherent, well-organised structures that correspond to the broad theories that scientists have? Although, the data from this research is limited, it does provide some indications of possible answers to these questions.

Firstly, there is the evidence from the research on light in section 4.11 that a sizeable minority of children were not consistent in the models they used to represent light at any one time. The effect of the intervention for the upper juniors was to make their responses *less* consistent. This picture is supported by the data in section 4.12 which shows that children's thinking is fluid with a majority of children, in 3 out of 4 instances, changing their representations of light and their explanations for vision between the pre- and post-elicitation.

More evidence for the effect of context in their understanding of electricity is given in table 5.8.4. The number of children who gave a consistent response of how to connect a battery to an electrical device was never greater than 65% in the pre-elicitation and *decreased* to a maximum of 35% in the post-elicitation. Even though there are many superficial topological similarities, the children perceived them as instances which they did not associate. This finding is supported by that of Andersson and Karqvsst (1979) who reported significant differences in children's ability to correctly show how to connect a festoon bulb to a battery compared to a MES bulb. Again over a longer period, between the pre- and post-elicitation, the data in table 5.11.1, 5.11.2.1, 5.11.4.1, 5.11.5.1 all show that children who consistently maintained one idea were a minority.

The absence of evidence from the research on processes of life for any context effect may appear to contradict such an argument. It undoubtedly supports Carey's (1985) view that between the age of 5 and 10, there is a growth in children's biological knowledge since the mean number of body parts mentioned effectively doubles from 2.7 to 5 across the age range. Table 6.10.6 also provides evidence that children are applying a more coherent, and therefore more limited, set of criteria to evaluate whether an object is living or non-living (Table 6.9.3.2, 6.8.3, 6.8.4). This, of itself, is not evidence for a consistent, theory like structure, but it does point towards the emergence of some more coherent understanding.

However, the real evidence for the lack of any such structures come from the work on astronomy where better data shows a lack of significant correlations between success/failure on items that would be related for an individual who held the scientific conception. Table 8.3.1a, and its continuation, table 8.3.1b, show how the responses for different items were correlated for lower and upper juniors. Infants were not considered in this part of the analysis as their level of understanding was generally low.

The data in these tables give a very definitive picture. For the adult scientist, most of these aspects of knowledge are connected in an interrelated whole. Yet these data show that for these young children, they were generally not. Thus it is difficult to conclude that these children had any strong theory binding their thinking together, and the much more tenable hypothesis, is that for the majority of children, their knowledge consisted of *fragmented pieces*, components of which were *partially related*. Strong associations were only found where there is, by the nature of the idea, a clearly defined relationship anyway. Therefore knowledge of day, month and year length are strongly related as is knowledge of the movement of the Earth and the time it takes to go round the Sun.

There is some evidence of relationships emerging in the knowledge of upper junior children which would imply that they were gaining a coherent theory of explanatory power as their explanations for day and night were significantly correlated with their correct/incorrect explanations for the daily movement of the Sun. Since the explanation of these ideas requires the mental representation of phenomena, and their manipulation, this data does point to the emergence of a possible model Nevertheless, it has only occurred for the upper juniors, and even for this group, the overwhelming majority of their knowledge would appear to be *unrelated.*

Relationship	*Lower Juniors Pre*	*Lower Juniors Post*	*Upper Juniors Pre*	*Upper Juniors Post*
Height of sun and length of day				*
Height of Sun and seasonal temperature variations		(*)[1]		(*)
Earth moves about Sun and Earth moves once a year		**	**	**
Explanation for why day length varies and correct model of motion of Sun	*	*	*	*
Model of the daily motion of the Sun and Earth and explanation for what happens to the Sun at night				
Lateral movement of the Sun during the day and the change in its vertical position		*		
Scientific understanding of the daily changes in shadow length and correct model of the daily motion of the Sun				
Explanation of how time can be told from shadows and knowledge of daily movement of the Sun across sky				
Explanation of how time can be told from shadows and correct response to the height of the midday Sun				
Explanation of how we can tell the time from shadows and responses indicating that the midday shadow will be shortened.	(*)			
Correct shape for the Earth and scientific conception of the Earth				

Table 8.3.1a. Significant correlations between aspects of children's knowledge about astronomy-part I.

1 Negative correlation

Relationship	*Lower Juniors Pre*	*Lower Juniors Post*	*Upper Juniors Pre*	*Upper Juniors Post*
Success on sorting cards by distance order with success on sorting objects in solar system by size		**		*
Scientific explanation of day and night and Copernican model of the annual movement of the Sun	—[2]	—	**	**
Scientific explanation of day and night and correct explanation for daily movement of the Sun	—	—	**	**
Scientific explanation for day and night and the scientific conception of 'down'	—	—	**	
Scientific explanation for the movement of the Earth and Sun and the scientific conception of 'down'				
Choice of shape to represent the Earth and the scientific conception of 'Down'				
Knowledge of day length and month length		**	**	
Knowledge of month length and day length	**	**		
Knowledge of day length and year length		*	*	**

Table 8.3.1b. Significant correlations between aspects of children's knowledge about astronomy-part II.

Therefore this study would definitely *not* support any hypothesis that there was a strong restructuring of the child's knowledge between 5 and 10 (Carey, 1985; Vosniadou, 1991). At best, there is some evidence of accretion, in that aspects of their understanding more closely approach that of the scientist, and there were more components to their knowledge. Such a development would be commensurate with Carey's notion of weak restructuring which she portrays as a process of knowledge accumulation with the generation of links and relations and no major paradigm shift. However, the data here only give support to the notion that children's knowledge grows during this period. It suggests that the bulk of children's knowledge would appear to be fragmented and consist of 'knowledge in bits' (diSessa, 1988). Even in contexts where there were close contextual similarities, children's responses varied implying that they failed to see the commonality of the two situations.

2 Correlations were not examined for this group as only very small numbers had successfully understood the models.

This view is supported by the work of Song and Black (1991), and the APU (1989). In an extensive review of the findings of the latter's work from 1980-1984 they note firstly that:-

> 'It proved exceptionally difficult to write questions in such a way that pupils responded appropriately to the demand 'describe the pattern'. Simply to ask 'what pattern do you see?' or 'what do these things have in common?' allowed too many opportunities for responses unconnected with regularity to be perceived.
>
> (Assessment of Performance Unit, 1989), p91

and secondly that:-

> 'The content and context within which the assessment investigation is presented act as significant cues to the pupils. It is the pupils existing framework and personal experience which determine the effect of the cues and subsequently affect the pupils' behaviours and the decisions they make.'
>
> (Assessment of Performance Unit, 1989), p133

Bloom(1990) also gives a good example of how the child uses simple observable features to generate 'a context of meaning' associating the wriggling of worms with 'hunting' - an action that animals do, and also using the metaphor of slinkies to explain its form of movement. Thus children are actively seeking out metaphoric association from their previous knowledge to construct a meaning. Brown (1987), basing her arguments on the work of Karmiloff-Smith and Inhelder (1974), also argues that for any problem space, a child will typically develop several juxtaposed theories that are adequate for various parts of the domain. Only when these procedures are functioning well, and the child becomes aware of inherent contradictions, can he or she begin the process of metaprocedurally reconsidering their ideas and reconcile the differences. Whilst this happening, there will be a developmental lull or even regression, a phenomena which was obseved in this research in children's understanding of how we see.

The contention here is that the meaning attached to the event is highly specific to the trigger provided by the context, and that even quite similar contexts provide different triggers. Thus the conclusion that can be drawn from the data here, and other reported work, is that not only that context is a significant factor in pupil performance, but that also, it is evidence for the lack of any coherent theory-like structures within their cognition. For the function of theory, or models, is to aid the observer to perceive the commonalities between what may seem disparate situations. The children's failure to perceive these similarities is therefore indicative of a knowledge which is based on a set of unrelated phenomenological primitives.

Instead, it would seem that children's knowledge *develops in a piecemeal and dynamic fashion*. Their knowledge is dynamic in the sense that new bits are added, lost or replaced as the child evaluates their significance and importance.

However, this complex process provides the material for the construction of unifying ideas which begin to unite these fragments of knowledge - that is for the formulation of inductive and theoretical generalisations. Without these partially adequate ideas, the latter cannot and will not emerge. Thus knowledge *does* matter.

However developmentalists argue that the emergence of such theoretical structures which resemble those of adult thought is explained by the ideas of genetic epistemology, and that knowledge accretion and conceptual development are subsidiary to this overarching process - the growth of a central cognitive processor. Do the data here provide evidence to support their general hypothesis?

8.4. The case for genetic epistemology

Monk (1991) has taken some of the data of this research collected for children's understanding of light (and others) and argued that changes observed in children's explanations of vision fit closely with the stages of development predicted by genetic epistemology. In essence, he argues that the explanations for vision can be categorised using the schema in Fig 8.4.1.

The basis for his categories is not elaborated but corresponds to the ideas proposed by Shayer and Adey's (1981) curriculum analysis taxonomy. He then compares the data for children's explanations for vision with the number of children predicted by Shayer and Adey to have access to the these mental operations. Table 8.4.1 shows the data used in his argument.

Whilst the fit is by no mean perfect, there is agreement in the broad trends and his case is strengthened by a similar analysis of the work of Ramadas & Driver (1989), Andersson and Karrqvist (1983) and Goldberg and MacDermott (1986) which also show significant associations. Monk (1991) has conducted a similar meta-analysis of children's understanding of electric circuits and produced more figures for his case, though not with the data from this research. His basic thesis is that although the data is not always consistent with the expected performance, it shows that the number of children understanding any one model is nearly always less than that predicted by the genetic epistemological limit which represents a maximal level for their cognitive capabilities.

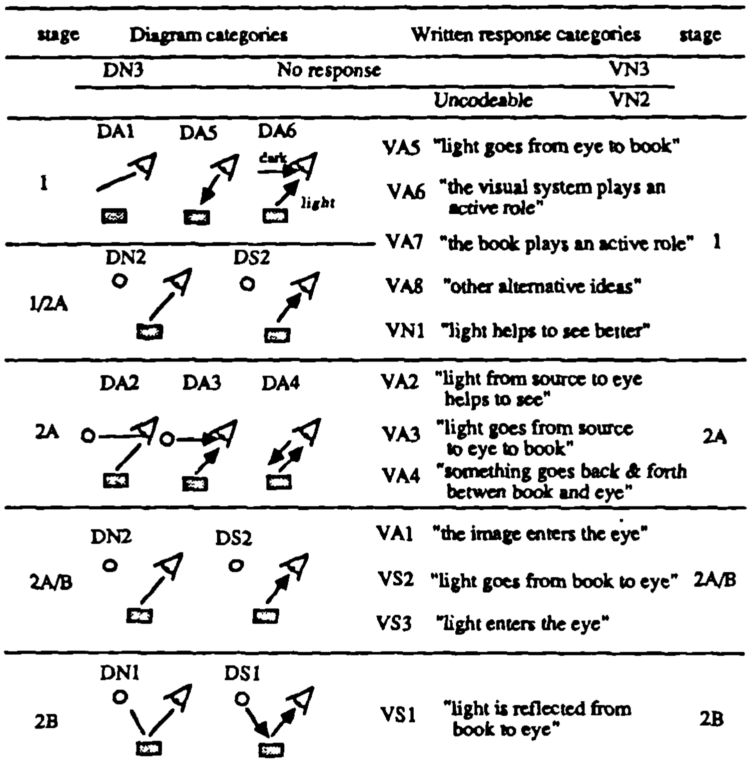


Fig 8.4.1: Categories[3] used by Monk (1991) in for his analysis

Further evidence to support such a view comes from the research into children's understanding of the processes of life. One of the questions used in the interviews asked children to complete a drawing to show what happened to food inside their body. There was a clear distinction between those children who failed to recognise any transformation of food, producing the drawings such as those in Fig 6.9.4.1a, 6.9.4.1b, and those who showed tubes linking the mouth and stomach/belly with food represented as a general paste, if at all. This finding is similar to that of Contento's (1981).

These drawings suggest that the former group have no conception of transformation of substance, and from a developmental perspective are at a pre-operational level of thinking because they are unable to conserve substance, one of the essential criteria used to distinguish between concrete and pre-operational thinkers.

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3 The terms DA, VA, DS and DN are mnemonics used by Ramadas and Driver (1989) for the responses they obtained.

Piagetian developmental stage	Explanation pattern	Percentage of children age 11 with access to such operations	Post-Interventions *Lower Juniors*	*Upper Juniors*
1	No explanation	12%	9%	0%
	Explanation without links			
2A	Explanations with single links	53%	74%	40%
2B	Explanations with dual links i.e. object-eye and source -object	32%	16%	60%

Table 8.4.1. Data on which Monk (1991) bases his argument

Table 8.4.2 shows the percentage of children who gave such responses in this research and the data for the proportion of children at the pre-operational level of processing predicted by the work of Shayer, Demetriou, & Pervez (1988) and Shayer, Küchemann, & Wylam, (1976). The trends in both sets of data are in broad agreement and consistent with the notion that these children are performing at less than their maximal cognitive capability.

	Inf-Post	L.Jun-Post	U.Jun-Post
No connection between mouth and stomach with untransformed food or no response as found in this research	41%	17%	9%
Predicted Percentage of children at no greater than the pre-operational level	22%	-[4]	7%

Table 8.4.2: Comparison of percentage of children who are pre-operational and the numbers showing food as untransformed after eating.

Another piece of data that is worth examining from this perspective is children's responses for the length of a shadow at midday (Table 7.10.2.2). To provide the scientific response to this question solely on the information presented, the child has to use compensation, arguing that as the Sun goes West, the shadow goes East and as the Sun goes up at midday, the shadow gets shorter. The genetic epistemological

4 There are no data available for children of these age and therefore no comparison can be made.

account would contend that such mental manipulations are only available to those who have achieved concrete operations. Table 8.4.3 compares the number of children at each age whose response shows that they could do this operation and the percentage of each group at different developmental stages.

	Inf-Post	*L.Jun-Post*	*U.Jun-Post*
Responses from this research showing shorter shadow attached correctly	42%	22%	74%
Predicted percentage of children with access to concrete operations	78%	85%	90%

Table 8.4.3. Comparison of percentage of children who have achieved concrete operations and the numbers showing the position of a shadow at midday correctly.

Here the general trend does not show such good agreement, though Monk would argue that the performance of the children merely shows that they are not reaching their maximal limit. However, the discrepancies are too large to be explained by such a hypothesis. Moreover, there are a number of problems with this perspective which are essentially that it fails to account for, or predict, the enormous variation in children's understanding from one context to another found in this and other research.

Whilst a strong case can be made for the developmental limitations on children's ability to perform formal operational thinking, it does not automatically follow that this is the 'key determining factor' on pupils' ability to learn science. Monk implicitly recognises this in discussing the data provided by Goldberg and MacDermott (1986) when he states that the failure of physics teachers to satisfactorily answer one of the set tasks can be explained by their tendency to 'assimilate the problem to the wrong schema'. Thus, the implication is that contextual or schematic knowledge *is* important in developing conceptual understanding.

The extreme position taken by some researchers in this field is that children differ from adults only in their accumulation of knowledge. Piaget's (and Monk's) work show that this position is untenable but the research of the alternative conceptions movement over the past decade has consistently shown that, despite the natural genetic epistemological development of children, it is schematic factors gained from pupils' experiences which *again and again* limit their ability to internalise the scientific explanation of a wide variety of phenomena. For instance, Millar and Kragh (1994) asked children about the motion of the same projectiles dropped in a closed and open car, about projectiles of varying mass dropped by someone running, and a bomb dropped from an aeroplane. Despite the contextual similarity of this instances, they were forced to conclude that 'children's responses were strongly influenced by the details of the situation they were being asked about' such as the speed of the carrier, the weight of the projectile, or whether or not the projectile falls rapidly, whether air is seen as having a significant effect and their familiarity with the situation. In conjunction with other instances (Andersson and Karqvist,1979) Kr discussed earlier, these results are a good demonstration of where questions, identical in all but the figurative details, resulted in different performance. This cannot because of any genetic epistemological differences, but because of different contextual clues.

Research has consistently failed to show generalisable levels of performance across contexts - the problem of décalage. For instance, the work of Hayes and Simon (1976) has shown that transfer only occurred on functionally equivalent problems, that is, where the contextual factors are similar. Chi et al (1982) noted in their work on problem solving that novices are seen as grouping problems according to the type of object involved, e.g. a 'pulley problem' or 'a falling object' problem, that is, they centrate on the schematic factors whose importance a genetic epistemological view discounts.

Historical studies (Wiser & Carey, 1983) of conceptual development support the view that the limitation on scientific achievement was not the failure to achieve formal thinking, but a lack of differentiation of concepts and structure within a domain which indicates the importance of the appropriate schema to an individual's ontogeny, or to put it another way, is it reasonable to argue that Aristotle's achievements were limited because he was not a formal thinker?

There are other examples which cast doubt on some of the premises of the genetic epistemological view and that question whether it is a complete description of the growth of the child's epistemology. For instance, Piaget claims that an a priori necessity for the distinction between pre-concrete and concrete operations is the ability to distinguish between the surface appearance and reality. Yet when Gelman and Markman (1987) pitted appearance against reality with a group of 4 year olds by using a problem of category membership for a bird that looked like a bat, 67% correctly used inductive projection to solve the problem. Whilst one study does not demolish a paradigm, it poses theoretical problems that remain to be explained and questions the claim that there is 'some kind of general processing mechanism of the mind which controls all comprehension' (Adey & Shayer, 1994) made for this school of thought.

The best that can be said for genetic epistemology is that it provides a *partial* account of *some* of the changes that are observed in children. It offers no account of the microgenesis of the many different ideas and concepts held by the children studied in this research - it simply places maximal limits on their capabilities and the concepts that can be introduced. Therefore, there remains large amounts of data for which it has no explanation. Why, for instance, do children conceive of vision as being an active process, see light as made up of particles, or that a bulb only needs a singular connection to a battery - what schemas have formed that drive such conceptualisations and how can they be changed?

Thus it must remain only *one dimension* of the complexity of content which confronts the learner and we must search elsewhere for accounts that might explain other dimensions to the origins of children's knowledge. This argument reflects a position that there is no theoretical stance in science education whose account is all-embracing, and that the explanation for how the child comes to know must remain at present an assemblage of differing contributory factors to account for the complexity of the child's epistemology. Only thus through a more comprehensive description of its origination, can our interventions have a greater likelihood of being well-directed, focused and effective.

Therefore, what other insights does the data offer into the child's epistemology? The dominant feature of the responses collected here, and elsewhere, is that their knowledge is situated in a particular context - therefore an examination of that context is important to see what are the formative influences in developing the child's understanding of the world. Two themes that stand out for particular attention are the role of language and metaphor, and the ontology of commonsense reasoning. In this section, data will be explored to see what justification they provide for the former.

8.5. Language and metaphor

An examination of some of statements used by children in this research does show the figurative use of language and the role of metaphor as a tool for expressing meaning. Many statements offered by children for explanation were denotative statements indicating attributes in the form of declarative propositions. These are commonly used for ontological entities with concrete properties and enable classification and prediction. Thus

'Electricity is dangerous' Daniel: Age 10

'When you push the switch, two wires connect to

each other and one of the wires goes to the bulb and the other goes to the cable.' Mark: Age 10

'It (blood) goes through your veins' Dustin: Age 6

However, there were another body of statements that showed children using language in a metaphorical sense, drawing on analogy to explain their meaning and possibly, using it to create mental models to represent physical phenomena that are not directly observable.

'Electricity is like magic.' Acima: Age 10

'Electricity is like gas...you can't see it, it is dangerous and it helps things work.' Wayne: Age 8

'Electricity is like lightning that comes from space - it hits the wires that are on the street and it goes to the top of your house and makes the telephone work. All the electricity goes down the control box in your house.' Farukh: Age 8

'It (electricity) must go very fast....faster than Concord because you can phone to France in about 10 seconds, so electricity can get to France that quickly.' Robert: Age 10

'Electricity is a very strong form of power, it runs all sorts of things...it would be hard to live without.' Harry: Age 10

Similarly, in the research into children's understanding of the processes of life, instances were found of language being used metaphorically. Thus the purpose of blood is to 'lubricate the joints' or 'keep your skin clean'. And, in attempting to explain how light travels and what happens to it when it hits a white card, the following child beneath draws on an analogy with moving objects and their interactions with material objects.

'It pushes the air out of the way and then when it gets on the card because the card is hard, the light can't get through so it gets stuck so you can see some light.'

Child. Age 9

The role of metaphor is best understood from the philosophical analysis of Harré (1986) that there are three types of entities that we experience in the world which require not a *singular* theory of science but a *triadic* one. Realm 1 theories enable classification and predictions about macroscopic objects which are tangible and accessible to sensori-motor experiences, i.e. concrete; thus a typical realm 1 theory is Newtonian kinematics. Realm 2 theories are iconic in the sense that they represent unobservable entities which are only accessible to our senses through instrumentation such as bacteria and viruses. The vast majority of scientific theories are descriptions and hypotheses of realm 2, e.g. explanations of the behaviour of matter in terms of atomic bonds and interactions, descriptions of the life and death of stars. Finally realm 3 theories describe objects for which there is no direct evidence of their existence such as quarks and black holes whose descriptions are essentially mathematical and wholly theoretical.

Metaphor is the tool that the subject uses to construct cognitive objects with iconic properties for a class of unobservable objects e.g. blood, electricity, light - those that Harré classifies as realm 2 objects which require a 'representation, in some medium or other, of a physical system and its modes of behaviour.' Hence metaphor, analogy and simile are the means which enable the development of scientific thinking.

The examples selected above show children attempting to do exactly this - construct an iconic representation. The constructions are personal, the tool is language and metaphor, and the referents are concrete, for in using an analogy or metaphor, 'the similarities from which it starts must be observable' (Hesse, 1963). The world of the concrete, and in children's case - the familiar concrete, is the foundation on which we construct the edifice of scientific understanding. Because -

> 'we derive our well-founded confidence in the reality of everyday things from the sensorimotor bodily experience of children, reinforced and brought to consciousness by *linguistic interaction with other people*[5].'
>
> Ziman (1979), p 120

Unfortunately, everyday language has many metaphors which implicitly introduce misconceptions - instances where our language lags behind our scientific understanding reflecting a commonsense interpretation of phenomenology. Thus 'he looked daggers at me', 'I caught his stare', 'She has got bags of energy', 'he has just run out of steam' or 'The battery has gone flat'. Moreover everyday descriptions are

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5 My emphasis.

based on a literal readiness to trust our sensations so 'He looked right through me', 'The sun rises' and 'Don't let the cold in' are all examples which are at odds with the scientist's understanding.

Therefore each word determines, and is determined by discourse. Learning science must become a process of understanding to transfer words from one context to another. The child must grasp that 'force' when used in the context of physics has a restricted and particular meaning which is quite distinctive from its use in the phrase 'he forced me to do my homework.' Both share aspects of a common reality but are translated through a process of metaphorical interaction. Since the fundamental questions and explanations of science depend on a good qualitative grasp of what is meant by such terms as 'energy', 'power', 'atom' etc, the teaching of science must give more emphasis to the opportunity for what Baird & Northfield (1986) have termed 'interpretive discussion', either between teachers and children or through peer-peer interaction - an aspect which is only implicitly and vaguely recognised in current pedagogy.

All of this evidence points to the requirement that science education needs to recognise the linguistic complexity inherent in the concepts and ideas it presents in schools. But it has to be remembered that our conceptual knowledge is constructed from our sensori-motor experience as a child. If so, and if we wish to understand the origins of the child's ontology and interpret their world view so that we can engage in a dialogue of meaning, what kind of understanding does it generate and what aspects do the data collected here reveal?

8.6. Commonsense ontology

The case for an ontology of commonsense reasoning has been made by a number of authors (di Sessa 1983,1985; Carey, 1985; Ogborn, 1985; Bliss et al, 1989). Bar the work of Carey (1985), all such accounts have restricted themselves to the domain of motion and dynamics. Such an approach has been most fully explored by Ogborn and Bliss who have made steps towards a formalisation of a psycho-logic of motion (Bliss & Ogborn, 1993). Their argument is that a child's knowledge is constructed from elements which can be considered as phenomenological primitives. Such primitives are the product of a set of basic sensori-motor interactions with the world which enable the construction of ontological entities which they term 'primitive actions'. These amalgamate into 'schemes' and 'rules', the latter being of a propositional nature. The combination of these two produce 'prototypes' which 'form a pattern of behaviour used to recognise, interpret and make predictions about motion' which form the basis of commonsense reasoning.

One of the essential 'primitives' is the notion of effort which is an essential agency of causality. Two possible sources of effort resulting in motion are suggested:

(i) Effort of another agent *on* the object

(ii) Effort *of* the object. This is effort preserved within the object, provided by itself, which sustains motion until it is used up.

However, it is useful exploration to apply such a model to other domains. Presuming that the domain of motion and its associated epistemology is the most well-established for the young child, it is highly likely that they will resort to this when asked to explain phenomena in from other realms of experience. Andersson (1986) has argued that such a set of primitives would form the 'experiential gestalt of causation.'

Hence when asked to explain how we see a book, the primitive of 'effort' offers a schema for explanation. For instance, such an ontology provides a possible causal mechanism for vision where the individual, as the agent, looks to the object to see, and in so doing, exerts effort which is towards the object, i.e - they act on the object. The use of such a schema would then explain why so many children in this research and everyday language hold the notion that vision is an active process from viewer to object. This perspective also explains why we find it so odd that aeroplanes fly as there is nothing visibly supporting them.

Similarly the data for children's explanations of day and night obtained for children's explanations could be explained by the subjects resorting to such a schema. Night is attributed to effort by the Sun which moves or goes down. Alternatively it is caused by effort of another agent, clouds which cover the Sun, the object.

The converse of these examples is those situations where this schema fails to generate a simple, economical explanation of the observed phenomena. Here it is possible that children are more likely to give no response.

The main additional evidence to support the arguments for a commonsense ontology in the child's reasoning come from the research on children's understanding of the processes of life. Carey (1985) has argued that the child's ontology commences with only a naive mechanics and a naive biology. In the latter, biological processes such as eating, having babies, growing are seen only as things people do, and are no different from playing, talking, bathing etc. The explanatory structure in which they are embedded is social and psychological so people eat because 'they are hungry', 'because they would die' or 'to keep healthy', but these are not biological mechanisms as such explanations are intentional, an aspect which also forms an important element of the 'prototypes' of Bliss and Ogborn (1993) (section 2.9).

The results of this research into children's understanding of processes of life clearly support such an argument. Table 8.6.1 shows the percentage of children's responses to the question 'Why do we need to eat' falling into the intuitive explanatory framework.

Such evidence shows that this intuitive explanatory framework is the baseline to which all children resort when confronted with a biological question where the context is not specified. Similar intuitive teological explanations were obtained in response to the question 'What does blood do?' where the majority of children suggested that it was to 'keep you alive.' and to a question asking 'What happens to the air we breathe?'. The responses to the latter question were more supportive of Carey's thesis that there is a restructuring of theoretical knowledge by age 10 as 43% of upper junior (age 9-11) responses indicated some understanding of the biological details as opposed to only 7% of infant (age 5-7) responses (Table 6.9.3.2).

	Infants	**Lower Juniors**	**Upper Juniors**
Intuitive explanations	97%	93%	97%
Biological explanations	0%	3.5%	3%
No response	3%	3.5%	0%

Table 8.6.1: Percentage of children providing intuitive explanations for why it is necessary to eat.

Furthermore, it is worth noting that there are aspects of children's knowledge which are remarkably unproblematic for them. Even infant children knew of a large number of sources of light, machines that used electricity and foods which are healthy. The features of this knowledge is that it is propositional in nature and directly accessible to their own concrete experience. There are no self-evident schemas with which it can be explained and it points to the notion that some knowledge is simply derived from experience in pieces which are unrelated to others.

Whilst the latter argument, and the others that have preceded in this section, may be speculative, it does point to areas that could be valuable for further research. For instance, Bliss and Ogborn argue that -

> ' a not inconsiderable part of human reasoning in general seems to be based on metaphors of effort, movement and support. An understanding of our ideas about motion may be one window onto more general kinds of reasoning.'
>
> (Bliss & Ogborn, 1993), p 39.

If this is the case, research that attempted to explore the mental schemes or models that children were deploying to justify their explanations would be valuable, particularly if it was able to show that such metaphors were common to a variety of domains. For in so doing, not only would it reinforce the importance of Bliss and Ogborn's analysis, but more importantly, it would give pre-eminence to children's *access to language* and their ability to draw on, and use appropriate metaphors as an *essential component* of their cognitive development.

Thus a series of questions arise for research into the development of children's use of language in science whose answers would provide more insight into the growth of scientific understanding.

- How do young children use language to talk about scientific phenomena?
- Are there techniques or structured exercises which would encourage children to talk about science?
- Would such techniques significantly develop their scientific knowledge and understanding?

The argument made here is that the development of children's facility with *scientific* language is one of the cornerstones on which a good scientific understanding is constructed. As yet, it remains largely unexplored and offers a fruitful avenue for further research.

8.7. Other achievements of this research

Firstly, it is worth stating what may almost seem self-evident, simply because the lesson of history is that the obvious is sometimes overlooked. This is that the data show that young children *do hold* a range of elaborated conceptions about the world in which they live and are able to articulate and communicate those ideas. On all occasions, very few children gave no explanation or no ideas about a phenomenon, and in general, children were willing and eager to discuss what they thought was happening. This does not mean that the child has a well-elaborated ontology with coherent causal mechanisms, but that their perception of the world is an active process in which the child constructs mental representations from their experiences.

However, it would seem that the development of knowledge with coherent understanding is a more elaborate process that requires initial differentiation followed by a process of integration.

As Hanson (1958) has shown, perceptions are theory bound and it is their existing ideas and theories that the child will use to act on, and interpret the world. Therefore, the finding that children do hold a wide variety of different ideas about physical phenomena is important, in that it means the teacher of primary science *cannot afford* to assume that the young child has no understanding of the world, for the data clearly contradict any such assumption. Moreover the notion of teaching by transmission becomes clearly unacceptable - for if the teacher's construct and theories are different, so is the meaning attached to their words by the pupils who have to interpret them. Sainsbury (1992) provides an elegant example of exactly this problem in a transcript of a conversation with a seven year-old as he observes a sheet of paper through a microscope.

P: It's got little hairs on.
T: What's paper made from?
P: Trees- oh you can see the wood

Sainsbury (1992), p 120

The pupil sees 'hairs' until they are given a new framework with which to decipher their observation. Just as education can fail because of the inability of the child to understand the teacher's thoughts, so can it fail because of an inability of the teacher to understand the child's meaning. The educational process has to be seen as a dialectic in which meaning is negotiated by a teacher who is sensitive to the typical frameworks of children's thought. Again, Sainsbury totally grasps this when she states

> 'For the most carefully prepared lesson will only be meaningful to those pupils whose personal understanding is ready for it. To bring about adjustments in each pupil's understanding, there must be a two way conversation in which existing understanding is revealed and new understanding actively entered into. It is only by interacting with the pupil, by negotiating a new shared meaning, that the teacher can be sure learning has been successfully achieved.'

Sainsbury (1992), p 122

Thus the significance of constructivist research has been the provision of a body of easily assimilable data (to which this thesis has contributed), which provides a comprehensive picture of children's thinking and a contribution to the insight necessary to undertake an educational process that consists of mediation between two partners, albeit that the teacher is a more knowledgeable one.

The recognition that this is an important approach to the teaching of science has enabled this research to attract funding which has led to the publication of a comprehensive scheme for primary science, Nuffield Primary Science (1994), consisting of 12 teacher's guides and 24 pupils books for KS2 and a separate set of publications for KS1. Each of the teacher's guides attempts to highlight and assist the process of negotiating meaning by including a chapter with suggestions for ways in which children's thinking can be elicited, a chapter which discusses typical ideas children often have, and a chapter of children's work which discusses how it can be interpreted for the processes of formative and summative assesment. The writing in these chapters was based extensively on this research and has been well-received so far.

8.8. The limits of constructivism

The path from the evident patterns in the data to the more speculative interpretations leads back to a re-examination of the theory driving this research itself. Issues that have arisen during the conduct of the research have revealed that the theoretical base has strengths and weaknesses which need to be recognised for the development and advancement of the theory

During the past decade 'Constructivism' or one of its many variants has become the dominant ideology in science and mathematics education and the grip that it holds on the research work in these domains is reflected in the almost exponential growth of research in this field (Duit, 1993). Space only permits a summary of this retrospective critique of this one dimensional approach which has acquired implicitly the status of a 'meta' or 'grand theory' (Lyotard, 1984) and the full version, given as a paper at the Conference on Learning Strategies and Misconceptions in Science and Mathematics Education, 1993, can be found in Appendix 8. These arguments have arisen from the experience of this research and reflection on the claims made for this approach to teaching. In so doing it contends that there is no justification for the hegemonic position 'constructivism' occupies within the science education community.

One of the problems of offering such a commentary is that 'constructivism' is a broad umbrella which is currently used for a range of diverse themes including both personal constructivism, social constructivism, social constructionism, constructivist pedagogy, and which is also applied across a wide range of domains from mathematics and science education to multiculturalism and research itself. However, the focus here is the notion of 'personal constructivism' prevalent in science education as defined in the generative model of learning (Osborne and Whittrock 1985), Driver's (1985) account of a constructivist approach to curriculum development, Tobin et al's (1990) description of an attempt to implement a 'constructivist' approach to teaching, White's (1988) position on the learning of science and some of the writings of Von Glaserfeld (1987, 1989) as he represents an influential theoretician for constructivism in science education.

Constructivism in science education has its roots in a reaction against two features dominating science curriculum reforms in the 1960's and 70's - an epistemology based on naive empiricism which was accompanied by a developmental stage-model of cognitive growth interpreted as implying deterministic limitations to children's capabilities. For instance, Driver and Easley (1978) argued that 'achievement in science depends to a greater extent upon specific abilities and prior experience than general levels of cognitive functioning'. In developing its case constructivism has focused very strongly on the resilience of learner's beliefs and the social construction of reality. Inevitably, when these features are in focus, there are other features which are blurred and out of focus, if not out of the picture altogether. The concentration on these issues has led to serious flaws in these constructivist's conception of science and science education.

Firstly as has been contended by several writers (Matthews, 1992; Matthews, 1994; Ogborn, 1993; Suchting, 1992), constructivist epistemology overemphasises the role of experience and sensation as a means of making new knowledge. The ironic consequence is the presentation of science as an empiricist activity, a view which is now widely recognised as fallacious (Feyerabend, 1975; Kuhn, 1962).

The second problem that arises for the constructivist approach is that the emphasis on the personal construction of knowledge and that the only check on the validity of such constructions is the extent to which they fit with experiential constraints (Driver, 1989; Glaserfeld, 1989) is essentially a relativist position. However, such a view of science is not commensurate with the views of science held by practitioners , who are predominantly realists, and fails to acknowledge the substantial case that has been made for modest realism by a number of authors (Hacking, 1983; Harré, 1986; Ogborn, 1994).

Furthermore, it leaves their epistemology without any methodology of theory adjudication. For if the only requirement of a theory is that it is 'viable' or 'fits' with experience, how is it to be decided that one theory is *more viable* than another?

Moreover, this relativist ontology has little to say to the science educator about the sequencing and complexity of content as there is no basis for deciding what makes one scientific idea more difficult than another. In contrast, the modest realist position, particularly that of Harré (1986) does offer an ontological position which would assist the development of a coherent curriculum.

Finally, constructivism makes the unfortunate mistake of confusing the epistemology of science, that is how new knowledge is made, with how children learn science which are not one and the same thing. For as Ogborn (1993) has elegantly argued, it is rather like saying that the only way to learn poetry is by writing poetry.

These criticisms are made because constructivism enjoys a domination in science education research which it does not deserve. What is necessary is a recognition of the successes *and limits* of constructivism. As Solomon (1994) points out, its major achievements has been to change the form of discourse used to describe children's ideas. In recognising that these were often 'misconceptions' or 'alternative conceptions', it has forced educators to acknowledge the child as an active epistemic subject rather than a passive recipient of knowledge. Thus is has begun to explore an alternative pedagogy, to which this research has contributed, which requires the learner to be active and which places more emphasis on teaching as a process of negotiating meaning in which discourse and metacognition becomes a much more significant activity. For only in externalising their thinking will the child become sufficiently self-aware to recognise a contradiction between their commonsense interpretation of phenomena and the scientist's world view. Such a process helps to sensitise the teacher to the child's understanding which enables a proper two-way interaction or what might be termed the cultivation of hermeneutical sensitivity in the teacher of the child's perspective. Furthermore, it has begun to explore aspects of what might constitute an effective pedagogy but that process is far from exhausted.

However, where constructivism overextends itself is when it adopts a flawed epistemology, confuses the epistemology of science with the learning of science and fails to recognise that it has little to say about the content and sequencing of the curriculum or how children might be told new knowledge. On the latter issue it remains silent.

8.9. Conclusions

Emerging from this thesis is a recognition that not one strand, but four strands of work are currently fruitful avenues for further research. And of these, one in particular - children's use and development of language, deserves particular attention.

The work of Jean Piaget and his followers have made a major contribution to our understanding of how children learn science. However, it is the contention of this thesis that there are limits to the applicability of this perspective, and valuable as his contribution has been to our knowledge of the development of the child's epistemology, there are issues and problems which remain unresolved or unacknowledged. Both it, and personal constructivism, suffer from an overemphasis on the capabilities (or lack of them) of the individual and fail to recognise the importance of the social aspect in the construction of new knowledge.

The theory of commonsense realism, most extensively elaborated by Ogborn (1994) has been very valuable in probing the origins of children's ideas and the roots by which it might develop. In particular, one aspect has pointed to the role of metaphor and language - the language traditions in which we live as being significant. For metaphor is a specifically linguistic process of concept formation, since a concept is altered or expanded when a word is transferred from one thing to another. Several authors have often pointed to the use of metaphor not simply as an adjunct to scientific thinking but central to the process itself (Harré, 1986; Hesse, 1963; Lakoff & Johnson, 1980; Weinsheimer, 1985; Ziman, 1979). Yet little emphasis has been given to this linguistic aspect of science within science education If it were, learning about science would be less a case of recreating and reconstructing a set of concepts from experience of the phenomena themselves, but more a process of interpretation and translation of unfamiliar and foreign ideas, in which developing understanding becomes a process of learning a new form of discourse, *constructing new metaphors to think with.* From such a perspective the learner

> 'must consciously bend his language, adapt his concepts and expand his universe of discourse by assimilating and fusing it with the other universe he wants to understand.'
>
> (Weinsheimer, 1985), p 223

Thus it is a contention of this thesis that the development of such a central plank of scientific thinking in young children remains largely unexplored. Opportunities to explore meaning and discourse do not feature strongly within the normal practice of science education (Davies & Greene, 1984) and have only been developed indirectly through the use of techniques such as collaborative concept mapping (Roth & Roychoudhury, 1994; Sizmur, 1994) in which the emerging map becomes a tool, or conscription device, for the negotiation of meaning between teacher and student. Yet, as the author has argued (Osborne, 1993), there is extensive room for introducing and developing the use of techniques such as the discussion of instance, key sentences, word association and DART techniques as similar conscription devices which would enable students to talk about science and negotiate their meanings with their teacher and peers. In this, this thesis would concur with Lemke who contends that

> 'the one single change in science teaching that should do more than any other to improve student's ability to use the language of science is to give them more practice actually using it.'
>
> (Lemke, 1990), p 168.

And that the exploration of such structured opportunities for talking and their outcomes would form a fruitful avenue for research.

The major achievement of this (and other) research has been twofold. Firstly it has provided a detailed and empirical elaboration of what the scientific understanding of the young child in primary school might be. In doing so it has helped to develop new ways of seeing, reinforcing the notion that these ideas are no longer 'mistakes' but 'alternative frameworks' (Driver & Easley, 1978;, Solomon, 1994). As such, it has facilitated the possibility of a better understanding of the child which is vital to the interpretive process at the heart of any teaching. Secondly, it has shown that such an approach when undertaken by ordinary teachers in the context of their own classrooms with no exceptional preparation can be effective in improving a child's understanding. A further analysis of the data of young children's understanding of astronomy also shows that there is little evidence for the argument that young children are using consistent or coherent theories, rather that their knowledge appears to be fragmented and context-specific. This research has also led to the development of a major curriculum project which offers the teacher a significant alternative to other approaches to teaching and learning.

Furthermore it has attempted to be critically reflective of constructivist principles as applied to science education in an attempt to define the limits of this theoretical position. In particular, it has pointed to the fact that the application of flawed epistemology may lead to a flawed or incomplete pedagogy. A good example comes from the UK Association for Science Education Teacher's Handbook (Ramsden and Harrison 1993), a significant book in that it represents the advice of the of the main professional body of science teachers. Here it is argued that teachers must start by 'finding what the learner's knowledge and understanding are' and give them 'opportunities to actively test and refine their understanding'. Yet in the long list of learning activities e.g. raising questions, making observations, using practical skills, small group discussion etc, not one mention is made of an activity which would enable students to be provided with a scientific theory. Yet the dialectic between theory and observation is an essential element to learning science so the scientists theories and frameworks must be provided, or to use Solomon's metaphor (Solomon, 1986) - children must be given the map and shown how to read it. Hodson (1990) as well makes this point elegantly-

> 'the simple matter is that theoretically uninformed observations *do not*[6] and *cannot* lead to the acquisition of new concepts. The claims for theory-free experimentation are nonsensical on both epistemological and psychological grounds.....In short, theoretical considerations must *precede* experimental inquiry.'

Additionally, the argument here has sought to show that the overemphasis on any one theory is a possible danger in that it 'obscures other perspectives, either by its popularity or its blandness' (Solomon, 1994). Instead there appears within the literature to be not one, but four avenues of exploration within science education which offer room to significantly improve our understanding of this process - that is research based Piagetian developmentalism, constructivism, commonsense realism and language and metaphor. It is the last of these that most urgently deserves particular attention for further work.

For if as Eger (1992) contends, the essential distinction between the nature of learning science and the nature of discovering scientific knowledge is one in which 'what the human being faces are not really the phenomena of nature themselves, but the various forms of written and spoken *text,* from lectures to research reports, to textbooks proper', a vital new focus for further research is the way in which children come to terms with this foreign language of science.

More importantly, if learning science is a process of interpreting the spoken and written work, then the act of teaching becomes a process of the 'negotiation of meaning', in which it is essential to 'cultivate the hermeneutical understanding' required to undertake this task. One of the major achievements of constructivist research so far has been to provide detailed descriptions of children's thinking which enable the teacher to view the world through the child's spectacles. The contention here is that the further development will come through recognising Eger's point that :-

> "... if we focus our attention not on science as research but on science *as knowledge* , as it faces us all when we *first encounter* it? Suppose we consider not the relation of humans *to nature* but their *relation to a particular science.* In that case, surely, what they encounter *is* a language already in being - the language of that science."
>
> Eger (1992), p 340

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6 Hodson's emphasis

Such a view means that the argument of Donaldson and others that the acquisition of language leads to cognitive development is at least *as*, if not *more important* than the notion that cognitive development leads to language development. However in taking this position, it is recognised that other avenues for research still havea significant contribution to make to the body of knowledge of science education, and that a research community should value diversity and heterogeneity, examining all ideas critically for their positive contributions, particularly those with pretensions to universality. This point need to be made simply because as yet -

> 'no one metaphor should be allowed to prevail (as currently the information processing metaphor prevails in cognitive psychology) and to become discursively hegemonic....New lenses of many different kinds would now seem to be needed - even if we can no longer supply the single God's eye view of things desired - the craft of the intellectual lens-maker to the public at large would still seem to hold some honour.'

(Shotter, 1992), p 11.

Appendix 1:

Contributions to the production of this Thesis

The overwhelming majority of the work in this thesis has been undertaken by the author, Jonathan F. Osborne. Chapters 1, 2, 3 and 8 are solely the work of the author. For chapters 4, 5, 6 & 7, the author was responsible for the coding and analysis of 100% of the data and the writing of the four research reports which form the substance of this thesis. Chapters 4, 5, 6 and 7 are essentially edited versions of those research reports which have been written solely by the author.. The author also participated in the collection a minimum of 25% of the data for each chapter.

Contributions by other individuals to this work are as follows

Chapter 4	Mr J. Meadows collected one third of the data Ms M. Smith, project officer, collected one third of the data
Chapter 5	Mr J. Meadows collected one third of the data Ms M. Smith collected one third of the data
Chapter 6	Ms P. Wadsworth, project officer, collected half of the data Mr J. Meadows collected a quarter of the data
Chapter 7	Ms P. Wadsworth, project officer, collected two thirds of the data

Professor Black acted as the project supervisor and the supervisor for this Ph.D research. As such, his role has never exceeded the normal requirements of supervision for a Ph.D

In addition, the research team contributed to the formulation of the methodology and the questions used in the elicitation and the trial and evaluation of the network.

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Appendix 3:

A Review of previous research into Children's Understanding of Astronomical concepts

A3.1. Introduction

The attractions of studying children's astronomical thinking are several and various. Just as astronomy was the earliest domain for scientific theorising, it represents one of the first areas of scientific thought where children are asked to transcend their concrete experiences and the logic of commonsense, for instance, the natural intuition that the Sun goes around the Earth. Instead they are expected to accept the seemingly less rational, and less justifiable arguments, that it is the Earth that spins and that people on the other side of the Earth do not fall off. Thus any research not only reveals children's domain specific reasoning, but how their thinking adapts and changes to the scientific world view (or not); therefore some researchers have been attracted to this domain to study the development in children's thinking.

The earliest research in this domain was undertaken by Piaget (1929) to explore the growth and development of children's knowledge and epistemology. One chapter of his work, *The Child's Conception of the World,* is devoted to children's explanations for the behaviour of the Sun and Moon.

Only in the last two decades has the topic attracted much attention again, principally from those researchers interested in children's alternative frameworks. These later studies have explored the child's conception of the Earth (Nussbaum & Novak, 1976; Nussbaum, 1979; Mali & Howe, 1979; Sneider & Pulos, 1983; Vosniadou, 1991), or alternatively, looked more broadly at children's knowledge and understanding of a variety of other topics e.g. their explanations for the rotation of the Earth, night and day and their estimates the relative sizes of the Moon, Earth and Sun (Klein, 1982; Jones, Lynch & Reesink, 1987; Baxter, 1989; Vosniadou, 1991).

For both groups of researchers, the principal attraction of the area has been the question of how the child comes to construct and use astronomical models which are counter-intuitive and unnatural. Historically, the phylogenetic origins of the scientific conception of the Earth and its movement through the heavens led to some of the most well-known conflicts between individuals and the established ideology of the time. However, since photographs now provide incontrovertible evidence that the Earth is a sphere, it cannot be argued that the development of children's thinking follows the historical development of ideas. So how does the child now shift from the naive 'flat earth' conception to the scientific world view? The work of the first group of researchers has led to the elaboration of a set of categorical descriptions of the development of children's thinking which describe a possible sequence of progression, and which differ from the work of Piaget in terms of the scope of and the sequence of the growth of the child's knowledge.

From the perspective of cognitive psychology the more fundamental question is whether the child's knowledge can be characterised in terms of elements of fragmented and unrelated knowledge, or alternatively, does the child hold a coherent theory? Secondly is any change dependent simply on the accretion of more information which leads to some minor or weak restructuring of their ideas or alternatively, are children operating with internally consistent naive theories which require radical restructuring to achieve scientific understanding?

A3.2. Children's Explanations

Nearly all researchers have used the clinical interview to explore children's thinking and from an analysis of their responses developed a framework which they have argued reflects progression in children's thinking. Whilst there are differences between these frameworks, it is possible to see commonalities. Piaget asked young children a series of questions such as 'How did the Sun begin?', 'What is the Moon like?', 'Why is there only half of it?' etc. Later researchers tended to use more specific questions based on the use of models or representational drawings so that part of the difference in their conclusions can undoubtedly be attributed to the differing methodologies.

From a thorough and systematic analysis of children's responses, Piaget proposed a three stage model of the development in children's thinking. In the first stage, children may say that the Sun and the Moon are made or produced by human or divine agents. Such explanations he characterised as 'artificialism', arguing that explanations of this type are generally a mixture of the 'artificial' where origin is ascribed to the intervention of an external agency, and the animistic where the objects themselves are given properties of life, consciousness and will. Many examples are provided by Piaget e.g.

> Caud (9;4)[1] : "How did the Sun start? ---*With heat.* --- What heat? ---*From the fire.* ----Where is the fire? --- *In heaven.* --- How did it start? ---*God lit it with coal and wood.*"

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1 These figures give the age of the child in years and months respectively

In the second stage of development, children's explanations for the origin of natural phenomena display aspects which are half natural, in that they are simply descriptive, and half 'artificial'. For instance, in the following example the child provides a natural explanation for the origin of the Sun and an 'artificial' explanation for the origin of the mountain.

> Font (6;9) "Where does the Sun come from? --- *from the mountain............* And how did the mountain begin? --- *it was people who made it."*

In the third and final stage, he argued that children's explanations shows that the origins of the Sun and the Moon are unrelated to human action.

> Aud (9;8) " What is the Sun made of? --- *Of clouds.* --- How did the Sun begin? --- *To begin with it was a ball and then it caught fire."*

Piaget argued that children's explanation of day and night followed an approximately similar sequence. In stage 1, sleep is the precursor and cause of night and the child is essentially unconcerned with 'how'. Piaget defines this as precausality because the child never seeks to explain 'how' the phenomenon occurs but simply 'why', ascribing causality to the underlying purpose i.e. it gets dark because we need to go to sleep. In his second stage, precausality remains but an explanation of the question 'how' has now been found. For example, night is seen as caused by a big, black cloud. The cloud does not block out the day and is not a screen - it is night itself derived from black air. In the third stage night is defined as a shadow produced by clouds blocking the daylight. Finally in the fourth stage, the children realise that night results solely from the Sun's disappearance though this does not imply that they know that the Earth spins on its axis. Children's progression was portrayed as a decrease in artificialism at the expense of a progressive search for explanations which identify causal elements (air, smoke, clouds, water) to account for the phenomena.

Jones, Lynch & Reesink (1987) identified five different explanations provided by children for the Earth-Sun-Moon system in terms of the shape, size and motion of these components.

Model 1 The Earth is stationary at the centre (geocentric). The Sun comes from nowhere in the morning and goes away at the end of the day.

Model 2 The Earth is stationary at the centre (geocentric) but spins. The Moon and Sun remain stationary.

Model 3 The Earth is stationary at the centre. The Sun and Moon rotate around the Earth.

Model 4 This is a heliocentric model. The Earth and Moon orbit around the Sun on concentric or the same orbits. With this model, children can correctly explain a range of phenomena but it is not the scientific model.

Model 5 The scientific understanding with the Earth orbiting the Sun and the Moon orbiting the Earth.

Only the first of these models bears any similarity to Piaget's findings but their work can be seen as extending Piaget's fourth stage. Their approach was to use clinical interviews based around a set of shapes of different sizes (spheres, hemispheres, circular discs, cylindrical rods, semi-circular discs, circles and semi-circles) with a sample of 32 Australian children from the third and sixth grade[1]. Children were asked to pick the shapes that most resembled the form of the astronomical object being discussed and to use their shapes to model the movements of the Sun, Moon and Earth during one day.

They point out that, of these 5 models, the latter four have their own internal logic and will successfully explain day and night and that they may form a hierarchy which represents children's progression. Applying a binary division into geocentric models (models 1-3) and heliocentric models (models 4 & 5), they found that children of age 11/12 were more likely to choose the latter and argued that this result reflects a progression in children's understanding. Their analysis of the chosen shapes showed that the grade 6 children were significantly more likely to choose the correct shape for the Sun, Moon and Earth, but that there was no relationship between pupil age and choice of an object of the correct relative size.

The framework produced by Baxter (1989) for children's explanations of day and night, from a questionnaire elaborates a set of six levels of explanation which are essentially a synthesis of the earlier work of Piaget and Jones et al. Table A3.2.1 show the percentage of children at age 9/10 holding each model.

Only a minority of children of this age have assimilated the scientific view and what is notable about his data is that, by the age of 15/16, it was still only a minority (47%) who gave the scientific, heliocentric explanation for day and night which is indicative of the strength and tenacity of intuitive explanations.

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1 These children would be age 8/9 and 11/12 respectively

Model	Percentage[1] %
Sun goes behind the hill	0.3
Clouds cover the Sun	9.0
Moon covers the Sun	9.6
Sun goes around the Earth once a day	16.4
Earth goes around the Sun once a day	45.8
Earth spins on its axis once a day	18.9

Table A3.2.1: Percentage of children age 9/10 selecting each type of explanation for the occurrence of day & night.

More recent work by Vosniadou (1991) categorised the children's explanations (age 5-11) that she obtained into 12 distinct types. However, many of these are refinements of the broad categories proposed by Piaget, Jones et al and Baxter. Consequently, the following summary is offered as a synthesis which would broadly summarise all of these findings of children's explanations for day and night and may represent a developmental sequence.

	Explanation	*Explanatory schema*
Model 1	Artificialistic explanations e.g. God makes it do that.	*Pre-causal thinking. Objects are purposive and actions are caused by external agencies.*
Model 2	Intuitive explanations and naturalistic explanations e.g the Sun goes away, clouds cover the Sun, the Moon goes behind the Sun.	*Explanation based on natural motions.*
Model 3	Earth is stationary and the Sun goes around the Earth once a day.	*Explanations based on natural motions. The geocentric argument.*
Model 4	The Earth goes around the Sun once a day.	*Accommodation to the scientific explanation.*

1 Baxter does not give actual figures for his data, but presents it in the form of a bar chart from which the percentages have been calculated.

Model 5 The Earth spins on its axis once a day. *Scientific thinking.*

A3.3. The Child's conception of the Earth

Probably one of the most seminal pieces of work in this domain is that undertaken by Nussbaum and Novak (1976). Their data were collected from a set of clinical interviews of 52 second grade, American schoolchildren. These children were asked questions about the shape of the Earth, the direction they would have to look in order to see the Earth and to predict the direction of fall of an object held by an individual located at different points on the Earth. Further questions were then used to explore the children's responses. From their data, they established a set of five notions or concepts which children commonly held about the Earth. These were defined as:-

Notion 1: The view that the Earth we live on is flat and not like a round ball. Children holding this idea did not explicitly state that the Earth is flat, but verbal probing revealed that they did not believe that we live on the surface of a large sphere. A commonly held idea is that there are two Earths, the one we live on and a spherical ball which is in the sky. This may be due to the association of spherical globes with the Moon and the Sun in the sky.

Notion 2: Children who hold this idea will state that we live on a spherical ball and suggest proofs of this idea such as travelling around it or viewing it from space. However, such children believed that objects would fall off the Earth from anywhere in the Southern Hemisphere and did not differ substantially from children who hold notion 1. When their belief was forced into conflict with their immediate sense perception, their commitment to the notion of a round Earth was revealed as weak.

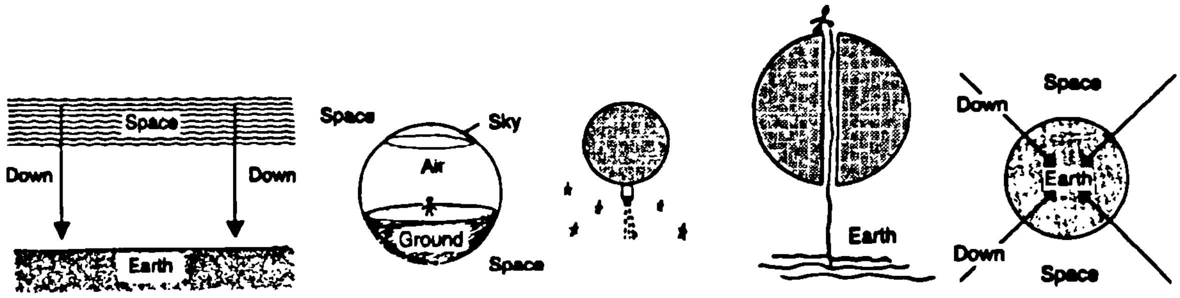
Notion 3: The thinking of such children was substantively similar to that of notion 2, the crucial difference was in explaining what would happen to water in a bottle located at the south pole. When asked 'Where would the water fall to?', notion 2 children said it would fall to the ground beneath whereas notion 3 children said that it would fall to the sky. Hence such children saw the Earth as being surrounded by the sky.

Notion 4: Here the idea is held that we live on a spherical planet and use the Earth as a frame of reference for up-down. However, children with this idea still showed some confusion in explaining in which direction an object would fall when dropped into the ground down mineshafts. That is, they had not fully internalised the concept of 'down' as the direction of the centre of the Earth.

Notion 5: Children who held this notion demonstrated a satisfactory and stable notion of the Earth as a planet which is a) spherical, b) surrounded by space and c) one where objects fall to the centre, i.e the scientific conception.

Further work by Nussbaum (1979) lead to the refinement of this framework. Notion 1 and 2 were conjoined and a new notion 2 introduced. In this notion, children saw people living *in* a huge ball composed of two hemispheres. They live on the horizontal plane in the bottom hemisphere and the top hemisphere is not solid. For the first time though, the Earth is seen as a finite body surrounded by space and Nussbaum argues that it shows a partial accommodation towards the scientific model.

The final set of notions are characterised by the diagram (Fig A3.3.1) which Nussbaum & Novak provide.



Model 1 *Model 2* *Model 3* *Model 4* *Model 5*

Fig A3.3.1: Diagram illustrating children's notions of the Earth concept and their progression.

Nussbaum and Novak postulate that such a schema represents a framework of conceptual progression although Nussbaum (1979) is more tentative about this hypothesis. Thus their work was an important contribution to establishing a developmental interpretation which has since become the basis for several replication studies, all of which have effectively confirmed their analysis (Mali & Howe, 1979; Sneider & Pulos, 1983) and in addition, attempted further exploration of children's understanding.

The extra dimension in the work of these researchers was to administer a set of Piagetian science reasoning tasks. The results from these tests showed that there were moderate correlations between performance on these tasks and attainment of higher notions of the Earth concept which were significant ($p < .01$). Thus these data support the argument that formal thinking may be a necessary, but not a sufficient condition for the development of scientific understanding. In contrast, Nussbaum and Novak argue that their results, which shows that some 8 year old children hold the scientific concept of the Earth, expose the weaknesses of a Piagetian-based developmental psychology which stresses age-dependent maturation of cognitive capabilities. They contend that to hold such a model would require abstract formal reasoning, which conflicts with the prediction of the stage model that virtually no children are capable of such tasks at this age.

Sneider and Pulos also explored the correlation between a wide set of other variables and found that the development of the Earth concept is correlated with the amount of schooling and access to other sources of information. This result simply supports the argument that the development of the scientific idea is dependent on a child being exposed sufficiently to such thinking. Otherwise, children will develop intuitive, commonsense rationale for astronomical phenomena.

Another novel aspect to Sneider and Pulos' replication study was to break down Nussbaum's model into two dimensions, a scale for classifying children's understanding of the shape of the Earth, and a scale for classifying their conceptions about the behaviour of gravitational forces on the surface of the Earth. From an analysis of data collected in structured interviews with 159 children from the age 10 to 13, they firstly confirmed that Nussbaum and Novak's schema was a good model of children's progression. Additionally, their methodology enabled them to show that there is a strong correlation between children's responses about the shape of the Earth and their responses about the behaviour of gravity, finding that the correct conception of the Earth's shape is the antecedent of understanding that objects fall towards the centre of the Earth rather than the reverse. Finally they confirmed that there was a strong age related trend in the development of the Earth concept but considerable variation within any specific age.

Their study also looked at the influence of a range of other variables measuring children's verbal reasoning, their spatial ability, field independence/dependence and their interest in geography and science. An analysis of these data showed that verbal ability was a highly significant predictor of attainment of the Earth concept at all levels. They conclude that children's ideas can be explained by characterising them in terms of a 'physico-cultural' concept where the acquisition of cultural concepts requires the relating of observable phenomena (e.g. that things drop down in the context of a flat horizon) with what the child is told about the world (e.g. that it is spherical and only looks flat because we see a very small part at a time) and argue that their data show that understanding of physico-cultural concepts is related to the development of the ability to use a spatial frame of reference and verbal reasoning.

Finally the model developed by Nussbaum & Novak was also confirmed by Baxter (1989) who asked children to draw the Earth, then to draw some people on it and then add some rain falling from the clouds. Typically many children's drawings showed horizontal clouds set against a context of a circular Earth with rain falling vertically to the bottom of the page.

The clear conclusion to be drawn from these studies is that this model is a reliable interpretation of a large body of data extracted by different methods. Secondly, the consistency of the data supports the view that it is a valid picture of the stages of development that children go through in acquiring the Earth concept. However, whether all children go through all stages or whether they make transitions across several stages is an open question which only a longitudinal study would answer.

A3.4. Other Astronomical Concepts

The core of the research work has looked at the child's conception of the Earth and their explanations for day and night. Only a few authors have gone beyond these areas. For instance, Baxter (1989) also investigated children's understanding of the phases of the Moon and the seasons using a mixture of interviews and a questionnaire. He found that the overwhelming majority of children's explanations of the phases of the Moon were based on the idea that the Earth cast a shadow on the Moon and, interestingly, the number who gave the scientific explanation essentially remained invariant between the age of 9 and 16. One explanation for this result could be the lack of treatment of this topic in many standard syllabi.

However, this argument would not apply to the explanation of the seasons which does feature in most science and geography courses. Baxter's data showed that the overwhelming majority at age 9-10 (≈ 74%)[1] explained the seasons in terms of the Sun moving nearer and further away. At age 15-16, 53% of children were still using such an explanation and further evidence of the poor understanding of the Copernican model comes from Durant, Evans & Thomas (1989) who found that only 63% of adults were able to state that the Earth goes around the Sun, and of these, only 34% of adults knew that the Earth took one year to orbit the Sun.

One possible explanation for the dominance of this view is a confusion generated by the idea that the Earth's axis is tilted. Some children may interpret the information that the

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1 Unfortunately, Baxter presents all his data in a set of bar charts where the data have to be inferred. Hence the accuracy of such figures is ± 2.5% at best.

Northern hemisphere is 'tilted towards' the Sun in summer as meaning it is nearer, and 'tilted away' in winter as the opposite. Technically such interpretation is correct and we are marginally closer because of the tilt. But the real reason lies in the change in the altitude of the Sun which is a consequence of the tilt. The result is that in winter the same amount of radiant energy is spread over a much larger area of land than in summer and hence, in winter, the land is much cooler. The development of this particular misconception might be avoided if greater emphasis was given to the elliptical nature of the Earth's orbit and the fact it is 2 million miles *further away* from the Sun in June.

One interesting task is reported in the research undertaken by Vosniadou & Brewer (1990) who asked children if they could identify the Earth and Sun in pictures of the solar system. Only a small percentage of infant children were capable of identifying the Earth but by top juniors around 75% of children[1] managed this task. Similarly only 25% of the American infant children could recognise the Sun from a picture as opposed to 88% of the upper junior children. However, no sample size is given for these data so it is difficult to place too much reliance on these results.

A3.5. The development of children's thinking

For very young children, Piaget argued that artificialism is an original tendency based on the idea that all things have makers who are purposive, as opposed to animism where things themselves are purposive. He saw children's responses as being based on mental predilections associated with images more than concepts, and that children initially see objects as made by makers who are purposive so that 'made *for* man' is transformed by the child into 'made *by* man' who uses such reasoning to ascribe causality to a whole range of phenomena e.g. day and night. This notion is the essence of artificialism which ascribes causality to human or divine agents. However, this is not a God or a deity as conceived by adults, but one in which the child sees the role of parent and deity as synonymous. Hence artificialism is a product of the filial sentiment. But this tendency weakens as the child acts on the world and begins to appreciate that only some acts are technically feasible and realises the limitations of their parents. As a consequence, the child's sense of their parents' deity diminishes and instead, the child seeks to explain things in terms of interactions between objects and a purposiveness which is inherent to the object itself - hence the rise of animistic thinking. However,

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1 Apart from the data reported for Greek children where only 20% of top juniors correctly identified the Earth.

such thinking is still based on a commonsense interpretation of phenomena and some authors (Nussbaum, 1976; Vosniadou, 1987, 1991) argue that the change required for the child to attain the scientific understanding is a revolutionary shift in the structure of their knowledge which is only possible by relinquishing their intuitive thinking. Since the latter is grounded in a well-established set of fundamental beliefs generated from everyday experience, such change is inevitably an extended process.

Vosniadou's interest in this domain is based on the contrast between the scientific view of the Earth, Sun and Moon and children's intuitive cosmology. She argues that the child's knowledge is based on certain experiential beliefs and that development of the adult concept requires radical change in the child's epistemology and ontology. Table 2.8.1 summarises the main aspects of her argument and is clearly supportive of her hypothesis.

She found that the key to conceptual change is the development of an understanding that the Earth is spherical and that it is possible to live on such a body without falling off. 80% of children who held such a belief were capable of explaining the phenomenon of day/night, a result supported by the earlier work of Sneider & Pulos who found that children who had such a concept of the Earth, also successfully explained the direction in which objects would fall. One of her key arguments is that children's knowledge is not fragmented since 85% of children made consistent use of one model in responding to a range of questions. But the conflict that is generated between the strong experiential basis for children's intuitive beliefs and the culturally accepted information does not lead to conceptual change. Instead, it leads to a progression in their misconceptions, e.g. a hollow Earth with an internal flat plane on which people live, as children try to resolve the conflict between their perceptions and their experience.

Evidence to support this view comes from an analysis of the data obtained from Nussbaum & Sharoni-Dagan's (1983) study of an instructional sequence delivered to second grade children in Israel. Children were assessed by interview before and after the sequence to determine what level of understanding of the Earth concept they had using the framework proposed by Nussbaum & Novak (Fig A3.2.1). Fig A3.5.1 shows the number of children holding each conception and the extent to which their ideas developed. Thus 17 children held model 1 and as a result of the instructional sequence, 1 child progressed two stages, 7 children advanced one stage and the remainder made no improvement in their understanding.

These data show that the majority of shifts were by one step and secondly, that the understanding of just under 50% of the children did not change. Vosniadou argues that the range of misconceptions is a result of a synthetic process by the child as it attempts to resolve its intuitive knowledge with the culturally accepted beliefs. Thus the child who views the Earth as a globe, where people live on flat planes inside the sphere, is able to reconcile his or her intuitive experiences with the ideas to which he or she is culturally exposed. Only the generative use of the Earth concept to provide explanations of physical phenomena will finally lead to resolution and acceptance of the scientific view but this does not destroy the intuitive concept, the two simply coexist. Such an argument supports Claxton's (1985) thesis that children simply operate with three sets of concurrent theories - gut science or intuitive reasoning for actions such as crossing the road, lay or popular science for explaining such events as atmospheric warming, and school science within the context of the school laboratory.

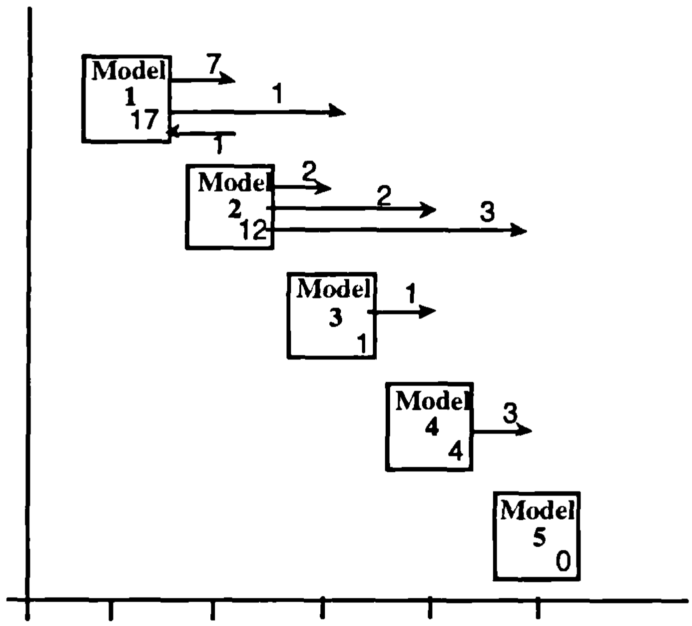

Fig A3.5.1.: Diagram showing the levels of children's understanding of the Earth concept and the amount of shift as a result of Nussbaum & Sharoni-Dagan's teaching sequence. The figure in the bottom right hand corner of each box shows the number of children holding that model initially. The figures above the arrows show the numbers of children moving to a new model and the arrow shows the extent of their movement.

Surprisingly, the role of language in conceptual development is only considered, amongst the literature cited here, by Jones et al (1987) who point to its influence in the formation of children's early ideas e.g. 'the Sun grew tired and went to bed behind the hill' or simply that the statement 'the Sun rises/sets' implies intention on the part of the Sun. Therefore everyday language simply reflects and reinforces children's animistic thinking and the commonsense observation that it is the Sun which moves across the sky and not the Earth which spins.

A3.6. Pedagogic Approaches

Only the work of Nussbaum & Sharoni-Dagan examines the effect of an instructional sequence on children's understanding and whilst many of these researchers recognise the value of their work to a constructivist approach to teaching science, few elaborate how the approach outlined by Driver and Oldham (1985) can be applied. Vosniadou (1991) does make relevant points about instruction arguing that there is a need for lessons to provide experiences and opportunities for children to consider how it is possible for a round object to appear flat. Secondly, the knowledge that gravity acts toward the centre of the Earth is crucial to the establishment of the concept of a spherical Earth. Until this is understood, it is impossible for children to see how they can live on a spherical ball and not fall off. She proposes two possible mechanisms for instruction - Socratic dialogue and the use of analogies, metaphors and physical models though without any evidence to substantiate the validity of such a pedagogy.

The fundamental problem for all teachers in this domain is that the relevant knowledge e.g. that the Earth is a sphere and rotates is not accessible to direct perception and investigation. Only when children are able to relate explanations of imagined entities e.g. enormous suns or barren moons, to the descriptions of the perceived phenomena will they be able to change their understanding. Thus the development of an understanding in astronomy requires the ability to transcend the concrete and abstract through the use of secondary sources. Baxter acknowledges this point in his statement that 'it is recognised that the construction of the heliocentric view involves a number of complex factors and it may not be appropriate to expect such an understanding before early adolescence'. When the latter factor is combined with Vosniadou's (1991) argument for the need to develop metacognitive awareness in children - that is to make them appreciate that their own ideas are naive theories, and the evidence for the limited effectiveness of instruction - it is apparent that conceptual development in this domain is a difficult and complex task for teachers.

If there are key concepts which have to be assimilated for a fundamental restructuring of ideas to occur, the pedagogic issue becomes one of how best to achieve such a process. For instance, Vosniadou & Brewer (1990) support general criticisms of Piagetian stage theory and argue that the changes observed can require a radical restructuring of domain specific knowledge, a thesis which was essentially proposed by Carey (1985) from her work on the development of children's biological knowledge. Thus any approach must aim to reformulate domain specific knowledge and the research reported here shared this perspective, being based on the general constructivist view that children's initial ideas are an important aspect of the process of assimilation and accommodation - important both to the teacher in assessing the initial level of the child's understanding, and important to the child who interprets new information using his or her existing framework of ideas. Only by providing opportunities for the teacher to elicit this information, and for the child to reflect on their own thinking and assimilate new ideas would there be any possibility of conceptual change.

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Appendix 4a

Elicitation Questions for Light

Activities A - F

A. Places where light comes from

EQUIPMENT REQUIRED — Drawing Paper; Pencils

Questions

1. Where is light coming from at the moment?
2. How does light get here from the sun?
3. What happens to light at night?
4. Draw pictures of all the things that give off light.

B. Reflectors

EQUIPMENT REQUIRED — Plastic Bicycle Reflector; Torch; Drawing paper and pencils; Tape recorder

1. Switch on the torch and shine it on the reflector.

   How do you think reflectors work?
2. Would the reflector work in absolute darkness?

   Why not?
3. Do a drawing to show how the reflector works when the torch is shone on it.

C. Torch and Mirror

EQUIPMENT — Torch for each pair of children; Mirror; Drawing paper and pencils

1. Activity: One child holds the torch which is switched on behind the child's head. The second child is seated and given a plane mirror. He/she is asked to use the mirror to see the light from the torch.
2. Do a drawing to show how you used the mirror to see the light from the torch behind you.
3. Show on the drawing how you think the light travels.
4. Is any light coming towards you?
5. How would you explain what is happening?

D. Torch shining on paper

EQUIPMENT — Torch; Piece of plain paper; Drawing paper and pencil

1. Switch the torch on and shine it at the piece of card.

   What do you see on the card?
2. How does light get to the card?
3. What happens to the light at the card?
4. Do a drawing to show what is happening when the torch is shone on the card.

E. Lighted Candle

EQUIPMENT NEEDED

Candle standing in sand tray
Matches
Drawing papers and pencils

Activity: Teacher lights the candle

1. Do a drawing to show how you see the light from the candle?
2. How far does light from the candle travel?
3. Could you see the candle burning from the other side of a big room?

   Why is this? Explain your answer.
4. How do you think you see the light from the candle?

F. Seeing

EQUIPMENT NEEDED

Matches
Book
Drawing of 2 pupils looking at clock
Drawing paper & pencils

1 (a). Look at the book. How would you explain to you younger brother or sister how we see the book?

(b) Do a drawing to show how we see the book.

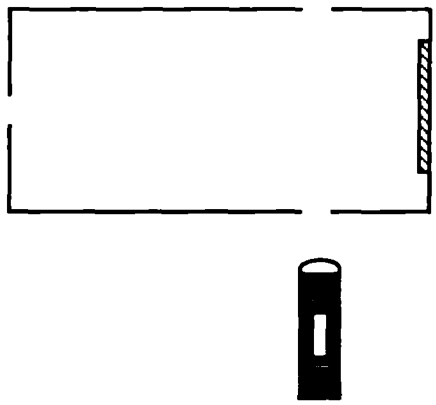
2. Explain what happens to our sight if there is no light. ?
3. How does light help us to see?
4. Look at the drawing beneath which shows two children in a classroom

   Add to the drawing to show how you think the children see the clock.

Additional Questions

The following are two additional questions that were added to the activities to be used in the elicitation after the intervention.

1. Look at this diagram. It shows a box from on top with two holes, a mirror and a torch. Add to the picture to show where the light goes.



Now add to this picture to show where the light is here.

2. Light is all around us. Write three sentences about light. Try and include the word 'light' in your sentence.

Appendix 4b:

Intervention Experiences with Light:Teachers' Notes

Bouncing light around a Table

Equipment Needed

Torch (Fairly bright, powerful torch needed)

4 Plastic Mirrors   Piece of white card
Plasticene

Aims

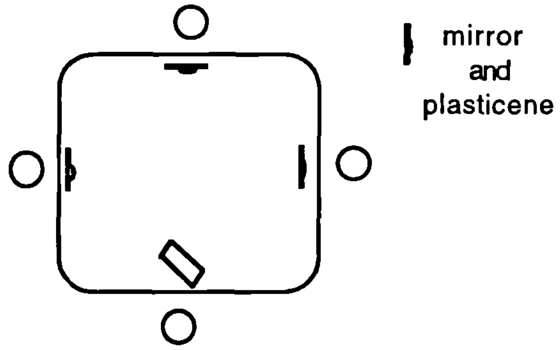
a) To introduce children to the idea that light can be reflected off shiny objects.

b) To develop the idea that light is travelling from one object to another.

c) To develop a model of representing light in drawings and diagrams.

This exercise should be posed as a simple game with light for children. The object is to send light from the torch by bouncing from one mirror to another till it is returned to the eye of the first person. The diagram shows the normal arrangement for doing this.

Children in groups of four, should be introduced to this as a problem/game which they are asked to hypothesise an answer to first i.e



How could we bounce the light from this torch around the four sides of the table?

The activity can be structured by dividing it into four tasks:

Activity 1: Draw a diagram to show how you think light from the torch could be sent around the four sides of a table.

Activity 2: Using the mirrors, see if you can do this as a group.

Activity 3: Draw a diagram to show how you managed to do this task.

Activity 4: Imagine that you are a scientist, trying to find out a bit more about light. What would this activity have told you about light?

Investigating Shadows

EQUIPMENT NEEDED

Torch	Plasticene
Small Stick	Pencil
Ruler	Card
Scissors	Paper
Shoe Box	Sellotape
Cocktail Sticks	

Aims:

a) To develop the idea that light is travelling from one object to another

b) To develop a model of representing light in drawings and diagrams

c) To provide an opportunity to examine the idea that shadows are formed by blockages of light.

d) To develop the idea that sharp shadows form because light travels in straight lines.

The shadow activities can be presented as prediction exercises. The children can be asked to guess or predict where different sized shadows form and then test their predictions. This allows them to challenge their own ideas and develop them. Children can work in pairs or groups for these activities .

Before the activity, the children can be involved in group discussion provoked by such questions as

What produces a shadow?

When do we get shadows?

Are shadows sharp or fuzzy?

Why are shadows sharp?

Children should have an opportunity to discuss these questions and record their ideas.

Discussion can be followed by the following tasks.

Activity 1: Draw where you think a shadow will form when a torch is shone on a pencil.

Activity 2: Try out this activity. Record your result.

Activity 3: Draw where you think a torch should be held to obtain

a) A shadow which is larger than a pencil.

b) A shadow which is smaller than a pencil.

Activity 4: Try out this activity. Record what you found out as drawing.

Activity 5: Where can you place a torch so that it shines on a stick and produces no shadow?

The Light Boxes Activity

EQUIPMENT NEEDED

1 Shoe Box

Mirror

Torch

Aims:

a) To provide children an opportunity to explore how light travels.

b) To develop a model that light travels and travels in straight lines.

c) To see that light can be bounced off mirrors.

d) To observe that light cannot be seen travelling from one place to another.

The light box has two small holes on opposite sides, a viewing slot and a small mirror taped to the inside back wall.

First ask the children to guess what they think will happen to the light when the torch is shone into one of the small holes. A worksheet is provided with suggestions for activities which can be used here.

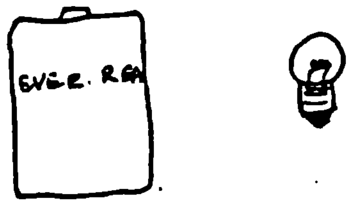
The activity can then be done with the children working in pairs - one child looks through the viewing slot, preferably in a dark or shaded room. Another child shines the torch into one of the holes, first directly across the box, then at an angle onto the mirror. The children then swop roles and can be asked to discuss what they saw, where they thought the light was in the box and whether they had changed their minds from their original guesses. They can repeat this activity, looking into different holes until they are ready to complete the second activity. In this they are asked to complete drawings of the inside of the boxes showing where the light is, and whether they have changed their minds now that they have used the boxes with the torches.

Appendix 5a:

Electricity Elicitation Activities

The following questions were used as the basis for the elicitation activities with children.

1. Where does electricity come from?
2. What do we use electricity for?
3. The drawing beneath shows a battery and a bulb. How would you get the bulb to light up?

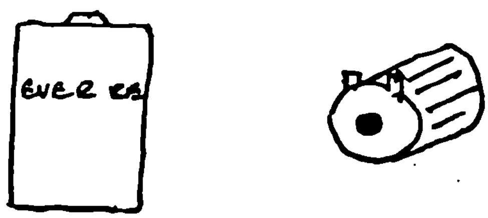


4. How could you make the bulb light up using only a battery and one wire? Use the space below to do a drawing of your answer.
5. Write three sentences about electricity.

   (Tell me three things about electricity. (infants))
6. What is electricity like?
7. Will the following things let electricity pass through?

YES	NO	DON'T KNOW
Wax		
Plastic Comb		
Cork		
Scissors		
Aluminium Foil		
Paper Clip		

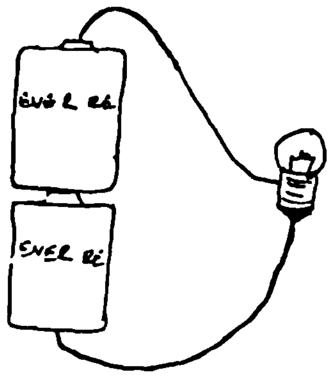
8. This drawing shows a battery and a motor. How would you get the motor to work?



9. How fast does electricity go?
10. How does a switch work?

11. How would you test if a comb would let electricity pass through?

12. In the drawing, a bulb is wired to two batteries. What would you expect to see?



13. How does electricity get here ?

14. What is the difference between electricity from batteries and electricity from plugs?

Appendix 5b:

Intervention Activities - Electricity

The following are a summary of the notes provided to teachers about the intervention activities to be used. Teachers were provided with an opportunity to try all the interventions at an in-service meeting. The importance of providing a stage for each activity in which children could discuss the task and consider their own thinking was stressed. Teachers were asked to encourage children to generate their own investigations to explore their understanding of electricity. These activities were provided as a support for teachers to use with children when judged appropriate.

Notes provided to teachers

The following notes are a guide to the main work that we would like you to do with your primary children on electricity in the next month. The aim of this work is to

a) Develop an understanding in children that two connections are needed to make an electrical device work.

There are two subsidiary aims

b) To introduce the notion that there is a complete path from the battery to the device and back again to the battery which is called a circuit.

c) To develop the idea that there are possibly certain features which are commonly used to describe electrical supplies such as voltage and +(plus) and -(minus).

It is important in this work that the children *have an opportunity to test their own ideas out* as to how the electrical devices work. Whilst we see your role as providing guidance and assistance and suggesting possible solutions when they are stuck. Please give the children an opportunity to test whether their own ideas work before intervening and offering alternative solutions.

The following is a description of the suggested activities and an explanation of any of the difficulties that you may counter. Please try as many activities as you can. At the back are sheets that you may wish to use with the children to guide them through the activity.

Activity 1: Making Connections

This activity is designed to provide children with an opportunity to look at a wide range of electrical devices and see if they can get them to work. Each device requires two connections from the battery to the device to get it to work and this is the point that we hope children will observe. However, please do not force it but provide them with a wide range of experience so that they can develop this understanding themselves.

a. Lighting a bulb

Apparatus needed: Battery, bulb, wire, connectors

Pupil Activity: Before giving the children the apparatus, ask them to discuss how they think they will get the bulb and to do a drawing showing their ideas. *Please keep any such drawings with their names on if you can.*

Now give them the apparatus and let them try. Ask them to do a drawing to show how they did it. Give them some help if they really get stuck. Ask them how many connections were needed to make it work.

b. Making an electric motor work

Apparatus needed: Battery, buzzer,

thick copper wire, connectors.

The instructions for this are exactly similar to those for lighting the bulb. The motor works with the battery connected either way. However, they should be able to spot that the motor goes the other way round when the battery is reversed. This may possibly lead to the idea that the electricity has a direction. When it goes through one way, it makes the motor go one way, when it is reversed, the electricity goes the other way round which makes the motor go the other way round.

Again, please keep any drawings that they do.

c. Making a magnet with electricity

Apparatus needed: **Large Battery** nail

insulated wire connectors.

Small needle or something which will be attracted by a magnet.

For this activity, the children will need the large battery. This is because to make an effective electromagnet, a battery which is capable of driving a higher electric current is needed. There is still nothing dangerous about it as the voltage is only 9V and you need to get to about 80V before you can begin to get a shock.

Ask children to discuss in small groups how they think they would do make a magnet with electricity and ask the children to do a drawing first which shows and then let them have a go. If they do not succeed, then please show them how to do it by wrapping a wire round the nail. The more turns the better and they should be using a piece of wire about 1 metre long as this will limit the current. The wire should not be left connected for too long as it will get hot and they can burn themselves.

Again they should be able to tell you how many connections they had to make in order to get it to work. Please get them to do a drawing showing how it worked.

d. Making things hot with electricity

Apparatus needed: **Large battery** two wires

steel wool.

The large battery is needed for this activity as well. The children should be able to suggest how many connections they will have to make to the steel wool to pass electricity through it. Again ask them to do a drawing showing how they think they could use electricity to make the steel wool hot and then let them try it on the apparatus.

The correct solution is shown below. The wires merely need to be touched to the steel wool which should then get very hot and burn. The amount of heat generated is very small so there is no danger of anyone burning themselves.

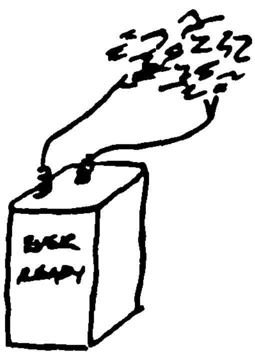


Fig A5.1 Diagram showing how battery should be connected to steel wool.

Again, please get them to consider the question of how many connections are needed and do a drawing of how they succeeded.

Activity 2: Investigating wires, lights and batteries.

The purpose of this activity is to get the children to look more carefully at a variety of electrical components to develop a broader knowledge about electrical components and reinforce the idea that electrical devices need more than one wire to make them work.

a. Investigating wires

Apparatus needed: Selection of mains wires.

Scissors.

The children should be invited to speculate what the inside of the wire looks like and do a drawing of it. Then let them have the wire which they can cut open. Ask them to do a drawing of it.

Is it what they expect?

Why do they think there is more than one wire?

(Please remind children that on no account should they do this with a real wire. They risk killing themselves!)

b. Investigating bulbs

Apparatus needed: A large clear bulb or small torch bulb

A magnifying glass

Ask the children if they have ever looked inside the bulb.

What do they think it would look like?

See if they will do a drawing of what they think it looks like.

Now give them the apparatus and ask them to draw what they see. Is it what they expect? How many wires into the bulb are there? Is this what they expect?

Get them to look at the top of mains bulbs if you are using those. What is written on the top? If you are using torch bulbs, what is written on the metal casing where it joins the glass?

c. Investigating batteries.

Apparatus needed: A range of batteries of different sizes,
bulb
wire

Ask the children to look at the batteries.

What do the batteries have in common written on them?

Get them to do a drawing of each battery and write the common features under each one.

Now let them try lighting the bulb with the batteries. You will need a 4.5 V bulb supplied by us for this as these do not blow even if you use a 9V battery.

Is there any pattern between the brightness of the bulb and anything that is written on the batteries(The connection is that the higher the voltage, the brighter the bulb)

Let them see if they can use two batteries to light the bulb.

What is the effect of two batteries?

Electricity: Where does it come from?

The following are suggested activities to be used in the intervention to increase pupil's understanding of where electricity comes from and how it is made.

Activity 1

Ask pupils to find out where electricity comes from and how it is made. Start by asking them to discuss their ideas in a small group and present them to you on a piece of paper. Then ask them to find out what the answer is. They can ask at home, use books at school, home and the library.

Please can you give them some time to come back with the information which could be written.

Posters could be produced on how electricity is made and where it comes from.

Activity 2

The materials include a hand operated dynamo. Turning the end of the dynamo rapidly will produce sufficient current to light the bulb very briefly. A more sustained output can be provided by running it along the bench.

Children can be given the following questions to discuss.

When does the bulb light up?

Why does the bulb light up?

How long does it take the bulb to light up after turning on the dynamo?

Where are the two connections? One of the connections is very obvious and breaking this means that the bulb will not light. The other connection via the metal body of the dynamo is not self-evident and can the children show that there are really two connections by breaking the second one. This would mean undoing the bolt which may get lost unless looked after!

What happens if you undo the bulb? Is it easier or more difficult to turn. It should be more difficult but only just and you do have to know this to really be sure. However see if children can spot this. What it shows is that you have to work to produce electricity.

Useful Reference books for children

1. Visual Science. Electricity Alan Cooper Macdonald Educational 0 356 07113 6
2. Let's Do Science: Magnets and Electromagnets. Malcolm Dixon. Edward Arnold 7131 09068
3. Science Exploration: Magnetism and Electricity Ken Hutchinson. Evans 237 293250
4. My favourite Science Encyclopedia. Hamlyn 0600 388 61 1

Conductors and Insulators

The aim of this exercise is to provide children some experience that some materials will let electricity pass through while others will not.

a. Testing for materials that let electricity pass through.

Apparatus needed:	Bulb, batteries, wires and clips
	Variety of different materials including some metals.

Provide children with a selection of materials and tell them that you want them to find out if electricity will go through the material. Ask them to start by discussing how they will use the equipment you have to test it and to discuss with each other whether they think electricity will go through. Ask them to record their answers.

When they have done this, they should be allowed to test their thinking with the apparatus. They may need help to set up the correct circuit. Ask them to record their answers. They should be encouraged to try a wide variety of materials from around the classroom. When they have finished ask them to compare their answers with their guesses and discuss any they got wrong.

b. Making a switch.

This activity is essentially a technological project to see if they can apply knowledge about electricity to making a simple artefact.

Apparatus needed	Bulb, battery, wire, clips,
	drawing pins, wood block, paper clips.

Tell the children that the circuit they have made needs a switch so that they do not have to hold the wires together all the time. Provide them with the bulbs and batteries but also provide the other apparatus and challenge them to make a switch so that the light can be turned on and left on.

Encourage them to discuss how they think it should be done before trying. If and when they are successful, ask them to try other materials in the switch to see if that will work. Ask them to record any successful solution.

Appendix 6a:

Elicitation Questions for Processes of Life

The following questions were used for the elicitation activities with children

1. Which of these are healthy foods? (Please ring)

   Lettuce sugar bread meat chips

   orange juice apples rice potatoes

   burger crisps biscuits

2. Which of these are to do with keeping healthy? (Please ring)

   running arguing watching TV feeling happy

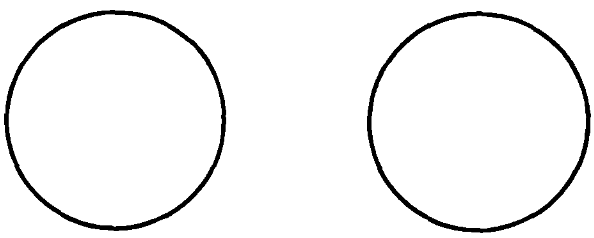
   eating playing with friends laughing

   swimming sleeping smoking fighting reading

3. Why do you need to eat?
4. What does blood do?
5. How is blood carried around your body?
6. What happens to the air which you breathe in?
7. Where in your body are your muscles?
8. Keep a diary of all the things you do in one day?

   Which of these are to do with keeping healthy?

9. Draw 4 things which are to do with keeping healthy.
10. On the diagram, draw a 'healthy meal' and 'a not so healthy meal'



A healthy meal   A not sohealthy meal

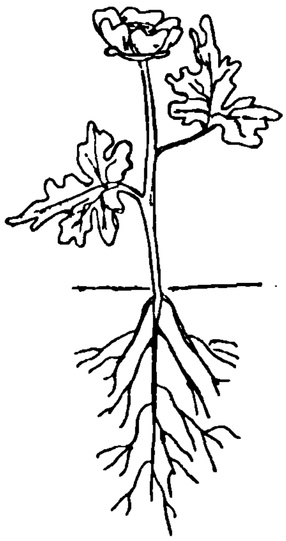
11. Add to the picture to show what happens to food and drink inside your own body

12. Add to the picture to show what else is inside your body.

13. Can you add to the picture to show where your heart is?

What does your heart do?

14. What are the parts of this plant called?



15. For each of the following, say whether it is living, once living or never living

Object	Response	Reason
A plastic box		
A piece of rock		
A spoon		
A plant		
An animal		
An insect		
An apple		
A toy car		
A seed		

Appendix 6a

Intervention Activities for Processes of Life

This appendix contains the notes which were provided to teachers for the intervention activities for processes of life intervention work. In the briefing provided to teachers, emphasis was placed on using a range of these strategies in any order that suited their work. Teachers were asked to encourage children to use these activities to explore their thinking and understanding of the processes of life and to use these as a focus for generating further pupil investigations.

A6b.1 Possible Interventions

The following is a list of possible strategies for developing children's ideas:

Group discussions - children can be given cards to sequence or to sort as a basis for discussion.

Data bases - these are a useful way of collecting and collating information and displaying it in a clear way so that the children can discuss it. They could take the form of:- sets (Venn diagrams), graphs (block graphs, tick graphs etc.) or computer data bases (Using programs such as 'Ourselves' or 'Our Facts'.)

Sorting/classifying activities - these help children to clarify their thinking, to work co-operatively and to exchange ideas. They could be simple sets e.g.. living or non-living, or a more complicated form of classification e.g.. Does it Move? Does it live in Water? (use the program 'Branch' -available as part of the MEP pack or as part of 'Junior Ecosoft'). Children can use these to devise their own classification tables or use ones which you devise for them. Logic trees ('decision trees' in the maths document ,page 37), are also a good way of helping children to classify using observable characteristics.

Devise their own investigations to test out their thinking. The children should have plenty of opportunity to devise their own investigations using a wide range of equipment which should be made available to them .

A6b.2. Specific Activities

The following is a list of suggested activities which can be used with particular topics.

Health education

Questions/activities that can be used with children to elicit their thinking

Foods:	Draw the meal which you ate last night.
	Where did the food come from?
Growth:	How do they know that they have grown?
	What helped them to grow? (Living things grow)
	What goes into your body?
	What do these things do? Are all of these things safe/healthy?

Group discussion:	How do healthy people look? What do they do? Make a message for not so healthy people. e.g.. Go to bed early.
Sorting Activities	Sort the list of words to do with keeping healthy as a group to see if they can influence each other. e.g.. laughing, reading, sleeping Which of these things do healthy people do -all of the time, some of the time, never? Make up a healthy day. Give the children cards to sequence.
Drawing/ Modelling Activities	Make class graphs to show which foods are healthy. use as a basis for discussion. How do we know these things? Make a class graph of the types of exercise taken. Use this as the basis for discussion.

Feelings

Group discussion:	What can I do to keep myself:- clean, safe, healthy? Who else helps?
Drawing/ Modelling Activities	Make a class poster to show things that make us feel good things that make us feel bad What are good feelings What are bad feelings e.g.. feeling sad, lonely, worried

Food

Group discussion:	What happens to the food which I eat? Use cards to sequence this. What connection is there between eating and going to the toilet?
Sorting Activities	Sort foods into fruits, bread and cereals pulses (beans and dried food), meat, vegetables, sweets and cakes. Which foods are :- fatty, sugary, salty

How our bodies work.

Investigat-ions	Children could be asked to feel their bones. if they have the opportunity to look at a model skeleton, are they able to feel where most of these bones are in their own bodies? Can they find out how many joints they have? Look at a large model skeleton and draw it. Find out what the parts are called. How many groups of muscles can they find? In the hall exercise each muscle group.
Drawing/ Modelling Activities	They could make a model to show how their arm bends. Make a model skeleton. (Learning through Science cards)

Blood and Heart:

Investigations	Can they feel their pulse? Use a stethoscope to feel their heart beat. What is the effect of exercise on heart beat and breathing rate?
Drawing/Modelling Activities	Make a model stethoscope

What is inside your body?

Investigations	*Kidneys:* -Ask the children to do some filtering to show how the kidneys work. *Lungs: Blow* up some balloons to find out what their lung capacity is.
Group Discussion	Hold a group discussion about the children's own pictures. Are they correct?
Sorting Activities	Place cut out parts of the body in the correct place on a large outline of the body.
Drawing/ Modelling Activities	Make a model stethoscope

Seeds.

Investigations	Ask the children to germinate some seeds to so that they are able to realise what the various parts of the plant do, particularly the roots. (Most of the children in the elicitation phase where unaware of what roots were).

Appendix 7a :

Elicitation Questions for Earth in Space

A7.1 Section A

1 a How long is a day?

b How long is a month?

c How long is a year?

2. Add to this picture to show, if you were looking towards the south, where the sun would be:-

a in the early morning

b in the middle of the day

c in the afternoon.

d. What happens to the Sun throughout the day?

3. a. What happens to the sun at night?

b. Can you explain (tell me) why night happens?

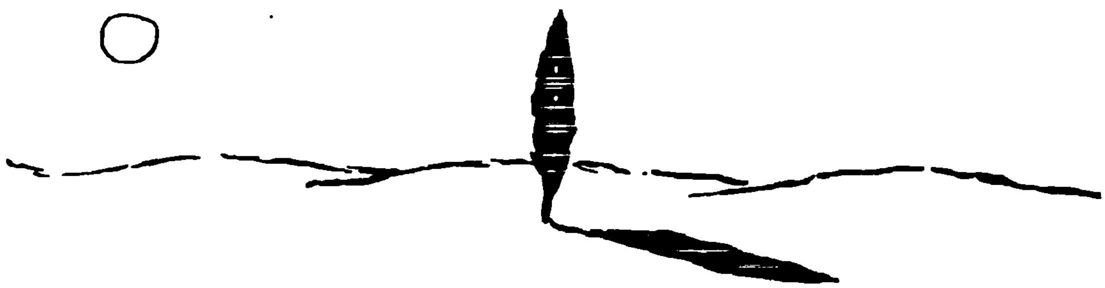
A7.2 Section B

1. How is a summer day different from a winter day? Can you think of three differences?

2. Here is a picture of a playground, you are looking towards the sun and it is the middle of the day.

   Can you add to the picture to show where the Sun would be in winter (W) and in summer (S).

3. Here is a picture showing a tree and its shadow early in the morning.

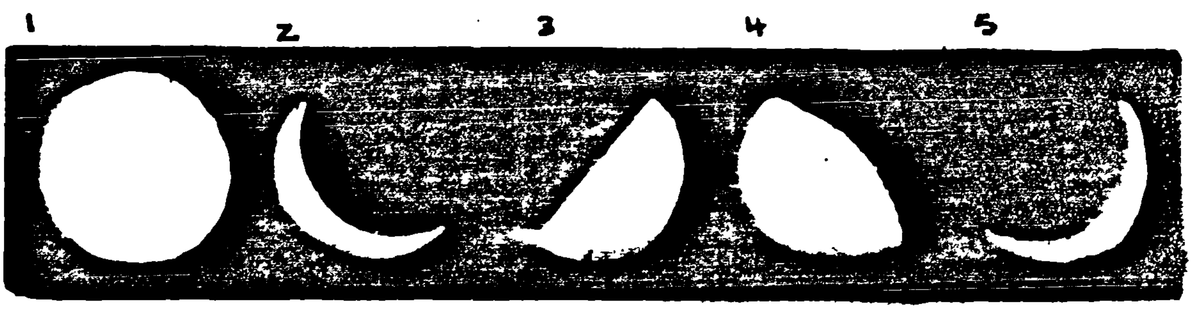


   a. Can you add to the picture to show where the shadow would be in the middle of the day?

   Use this space to explain (tell me about) your drawing.

4. Do you know how shadows can be used to help us tell the time?

5. a Here are 5 drawings. Which ones have you seen the moon look like?



   b (If more than two identified) Can you show me which one you would start with, which is second and so on?

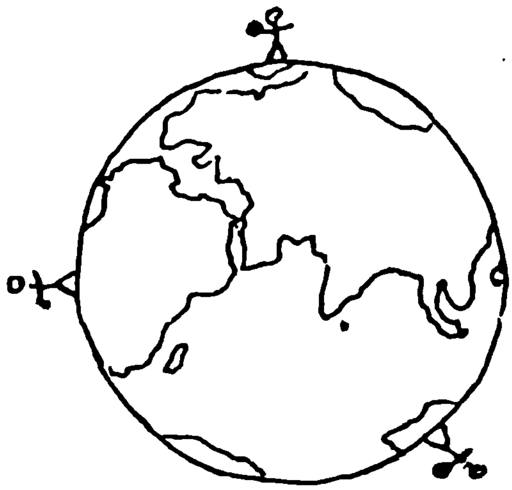
A7a.3. Section C

1 Look at this set of shapes.

a Which one do you think is shaped most like the Earth?

b. Can you explain (tell me) why you think the Earth is shaped like that?

2. This drawing shows three people on different parts of the world. They are all holding a stone. Mark on the drawing how the stone will move when they let go of it.



3. Imagine you are in a spaceship in outer space. You look out of the window; how would you see the Sun, Moon and Earth?

a Use this space to draw what you would see.

b Tell me about your drawing.

4 a. Ring or underline which of these you think are stars:-

Earth, Moon, Sun, Venus, Mars, Polaris,

Satellite, Scorpio, Alpha Centauri, Jupiter?

b. Ring or underline which of these you think are planets:-

Earth, Moon, Sun, Venus, Mars, Polaris,

Satellite, Scorpio, Jupiter?

A7a. 4. Section D

1 a. Choose two shapes from this set to represent the Sun and the Earth.

b. Can you show me what happens in one day and night?

(I'll hold one for you; which one would you like me to hold? If you want me to move mine, tell me how to move it.)

c. *(if child has given an answer to b. above)* Can you show me what happens during one year?

2* Using the shapes or by drawing, can you explain (tell me):

a. Why days are longer in summer?

b. Why it is hotter in summer than in winter?

3. a. Can you explain (tell me) what a star is?

b. Can you tell me one?

4*. Look at the set of 6 cards about distances. Can you put them in the right order, starting with the largest?

Can you tell me how far it is from London to:-

a. New York

b. The Sun

c. Margate (Southend)

d. The Moon

e. Mars

f. Liverpool

5*. Look at the set of 6 cards about parts of the Solar System (Sun, Moon, Earth, Jupiter, Mars, Saturn)

a. Can you put them in order of size starting from the largest?

b. Can you write each name in this table, starting with the largest and write how big you think they are?

	Part of the Solar System	How big are they?
a.		
b.		
c.		
d.		
e.		
f.		

* These questions were not used with infant children

Appendix 7b:

Intervention Activities for Earth in Space

This appendix contains the notes that were provided to teachers for the intervention activities. In the briefing given to teachers, emphasis was placed on using a range of these strategies in any order that suited their work. Teachers were asked to select activities that they considered appropriate to the child's understanding and encourage them to explore their understanding and thinking of the relevant concept further.

A7b.1. Time lines

This activity aims to encourage children to think about themselves and their lives as a series of events related in time. Many of the concepts associated with Earth in Space depend upon the pupils having some idea about time, from length of days and nights to ideas about months and lunar cycles to understandings of years and the seasonal changes that occur during a year.

Description

For all ages from 5 to 11 years - make a time line for a short period, initially a day, in which to record some information about memorable activities and events and times at which they happen. For infant pupils, this could be done without mention of clock time, but with reference to major breaks in the day e.g.:-

Leave home - arrive at school - first play - lunch - home time - playcentre - bed time.......

For older children, develop this into a time strip or time line covering longer periods e.g. a week, a month or a year showing events in order and dates. This could be developed further into a time strip for the whole of a child's life. A sample strip is shown beneath. Children add events to the boxes, either as pictures or in writing.

Monday	Tues	Wed	Thurs	Fri	Sat	Sun

Timeline for a week

The activity involves drawing a line or producing a strip chart. One end represents the beginning of the period being studied and the other the finish. Children then mark on the chart events in their relative position. So a chart for the year could have Christmas, my birthday, holidays, sister's or brother's birthdays on.

This activity or something similar is important in that preliminary findings show that infant children have little understanding of the adult's segmentation of time.

Follow up ideas

Using 24 hour clock and pie charts of daily happenings.

Make a time line of some famous person in History (a Scientist?).

A7b.2. Discussion Activity

Explanation

The following activity is designed to encourage children to reflect on their own explanations for astronomical phenomena.

Description

Give the children a set of cards. Each card should have on it one of the following statements.

'The Sun goes to bed at night.'

'The Sun hides behind the clouds at night'

'The Sun goes beneath the earth at night'

'The Sun goes round to the other side at night'

'The Sun does not move. The earth does and we turn away from the Sun at night.'

'The moon shines because light from the Sun bounces off it.'

'The moon shines because it has its own light like a light bulb.'

(and any other statements that would be relevant)

For each statement, children should be asked to work in a group, stating whether they agree or disagree. They should also be asked how they know what they think is right and to record their evidence.

A7b.3. Directed Reading Activities

Explanation

Much of the information about the Earth and the Solar System has to come from secondary sources e.g. teachers, parents and books as it impossible to investigate some of the ideas being introduced here. Whilst books are valuable, the act of reading for information (reflective reading) as opposed to reading for enjoyment (receptive reading) can be encouraged by the use of directed reading activities which force children to return to a passage and extract information from it. Appendix 1 & 2 include some examples which can be used with children who are capable of reading i.e. lower and upper juniors.

Description

Give out the passages and ask the pupils to follow the instructions at the end.

Follow up activities

It is very easy to develop more of the Cloze procedure reading activities by using the computer program TRAY or similar programs. The text has to be typed in and children then buy letters and attempt to reveal the text. This forces them to think about the text and its factual content.

A7b.4. Shapes

Explanation

Many children have difficulty in describing the shapes of the Earth, Sun and Moon. This activity is intended to familiarise the pupils with a variety of 2 and 3 dimensional shapes, extend their powers of observation, enhance their vocabulary and make it easier for them to recognise and describe shapes.

Description

Collect a set of flat and three dimensional shapes, but mainly ones with round edges. Children should work in groups. One child should be given the shapes, either in a dark 'feely bag' or asked to take them behind a screen so that the other child cannot see them. The child with the shapes is then asked to describe the shapes and the rest of the group should attempt to guess which one of the following shapes it is e.g. a sphere, cylinder, disc, circle, rectangle, block or cuboid.

The group doing the asking can ask questions like:

- How many sides has it?
- How many edges and corners?
- Where have you seen shapes like this?
- How would you describe the shape to somebody over the telephone?
- With younger children, use a feely box so they can try to describe the shape which they can feel, but which is hidden from the others. Other feely box activities might include:
- Put four shapes into the box and provide a larger collection visible to the child. Ask the child to feel a hidden shape and then choose the visible shape which is the same.
- Ask the child to name, as accurately as possible, the hidden shape.
- Organise a group of children to ask ten questions of the child who is feeling the hidden shape, to see if they can identify it without looking at it.

Follow up ideas

With older children identify shapes in the environment and try to link shape to function. Attempt some mathematical classification of shapes which may describe the numbers of sides, edges and corners. Differentiate between the various "round" shapes, so that pupils begin to use more accurate descriptions like disc, circle, cylinder, sphere.

A7b.5. Scrap books

Explanation

Children need to relate the ideas about science they learn in school with the many influences they receive from the media. Collecting pictures and other items from magazines and newspapers will encourage them to think about how the ideas they are developing are used in the media and to help them to make sense of the impressions they receive.

Description

Collect magazines and newspapers. Ask the pupils to find and cut out pictures which show daytime or night-time, the Sun or sunsets or sunrises, moon, stars and planets. Ask them to stick these pictures into a large scrap book with some brief comments from the children. Scrap books could be a class scrapbook, a group scrapbook or individual ones. These scrapbooks can be used with infants as a stimulus for discussions in class or groups and with older children to stimulate investigations or writing about the Earth in Space.

Follow up ideas

Pupils can be encouraged to prepare their own books, using a variety of materials from magazines and their own drawings and written comments. Pupils might include in their own books information taken from other sources and present it in their own ways, e.g. charts on solar system information.

A7b.6. Draw an object

Explanation

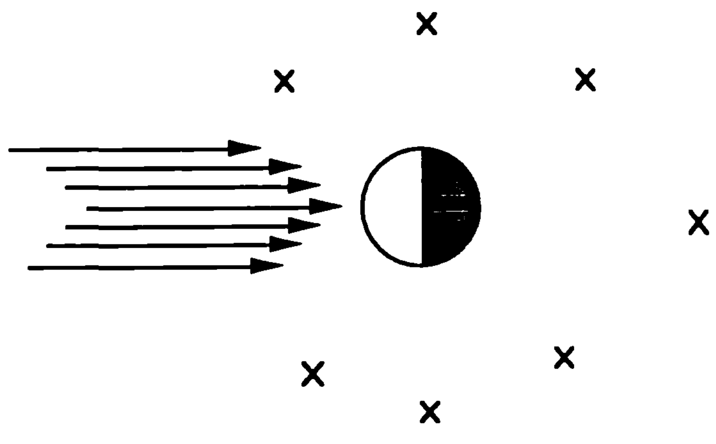
This activity is intended to encourage children to imagine things from other people's viewpoint as well as to observe things closely from their own perspective. Children often find it very difficult to lose their egocentric ideas and appreciate that things may appear different if you observe them from a different place. An example of this is the apparent movement of the Sun across the sky. The Sun appears to rise in the East and set in the West, whereas really what is happening is that the Earth is spinning and the Sun is still in relation to the Earth.

Description

Egocentric viewpoints - for younger children, ask pupils to sit in a circle round an object and draw what they see. Then compare the different drawings. Suitable objects for this exercise would be things which do appear different from various angles. A teapot might be suitable in this activity.

For older pupils, then try to imagine what it would look like from another child's position - draw it from the other viewpoint.

This activity can then be used with a torch shone onto a spherical shape which represents a globe. Children can be seated around the globe and asked to draw what the globe looks like from their position. (The crosses mark positions in which the children can be placed.)



A7b.7. Ordering the planets

This activity is designed to give the children a sense of the size and distance of the planets.

Description

Produce a set of cards, each with the name of a planet on it. Ask the children to use books to find out which is the largest, the next largest and so on so that they can put them in an order which corresponds to their size.

Then repeat the activity and ask them to place them in order of distance from the Sun.

Finally you can take them out into the playground and show them the scale of the distances.

Planet	**Distance From Sun** (millions of km)	**Distance Across Playground** (metre)
(Sun)	0	0.0
Mercury	58	0.4
Venus	108	0.7
Earth	150	1.0
Mars	227	1.5
Jupiter	748	5.2
Saturn	1425	9.5
Uranus	2869	19.0
Neptune	4490	30.0
Pluto	5837	39.0

If the playground is not large enough, the distances can be halved.

Taking a photograph is a useful way of recording the event.

A7b.8. Estimating sizes

Explanation

We want children to have some idea about the size and scale of the Solar System. Things which are near appear larger than things which are further away. This activity aims at making this more apparent to pupils. To understand that the Sun is a star (level 4) you need to understand that some things look large because they are nearer.

Description

Organise the children into small groups of six or seven. One child is the observer who stands at the front and the other children then distribute themselves about the room or the playground. The child at the front is asked to work out 'Who is the tallest?' and 'Who is the smallest?' without moving either themselves or any of the other children.

You can suggest that they try using their thumb for sighting purposes. However in reality, this challenge is impossible as you have to know how far away are the objects. Do not tell the children this but see if they can arrive at this conclusion themselves.

Then ask one child to be the Sun. This child should be placed very close to the observer. All the other children are stars and go as far away as possible. The child at the front then has to say whether

a) 'the Sun' and 'the Stars' look very different in size.

b) Whether they really are the same size and if so why do they appear to be different sizes?

Ask the children all to take turns at being the observer at the front. Their experience can then be used as a basis for discussing whether the Sun could be a star.

A7b.9. Other people's ideas

Explanation

By presenting children with the ideas of others, we want to help them compare their own ideas and see whether their ideas match up in explanatory power.

Description

Prepare a list of alternative views about the Earth in Space, which may arise either from historical and mythical ideas, or from the ideas of the pupils within the class. Present these to groups of children and ask them to discuss and come to some consensus about their own ideas on the issue. They should be asked to suggest how they could find some evidence to back up their thinking. Some suggestions for starting points:-

"Some people think the Earth is a flat shape, others think it is spherical."

"Some people think the Earth goes round the Sun each day, others think the Earth goes round the Sun once every year."

"Some people think the earth goes round the Sun, others that the Sun goes round the Earth."

"The ancient Greeks believed that the Sun was a chariot of fire, driven across the sky each day whilst the Egyptians thought the Sun was carried away at night on a boat to the other side of the earth."

A7b.10. Seasonal change

Explanation

This activity is intended to encourage children to notice and respond to seasonal changes through drawing, writing, painting, drama, etc.

Description

This is a sorting activity which encourages children to think about changes that occur from season to season. Give the children the following statements cut up as thin strips and then ask them to order them into groups. Let the children devise their own groups.

The days are hot	It gets dark at 4 o'clock
Daffodils are out	We go on our holidays
Snow falls	The leaves fall
Blossom is out	Birds leave for other countries
Roses are out	The days are cold
Lots of rain falls	The days are very short
The wind blows strongly	The Sun is high in the sky
The Sun is low in the sky	It is dark when I get up
Flowers are growing	Lambs are in the fields

When the children have finished they can compare theirs with other groups.

Using the tables of temperatures in major cities, they can be asked if it is hot everywhere at the same time. Ask the children to produce three groups (possibly upper juniors only).

Places the same temperature Places that are hotter

Places that are cooler

What pattern is there to the cities that are in the last two groups?

Finally children can then be asked to consider 'What causes the seasons?' Ask the children to see if they can find out or think of reasons why it gets hotter in the summer. Responses that say that it is because we get closer to the Sun can be challenged by saying that that does not explain why the Sun gets higher in the sky in summer.

A7b.11. Log books

Explanation

A log book is something used by the pupils to make records of things that they observe over a period of time. They are also used by children to record their ideas about what they observe. Ideally, the entries in log books should be dated, so that the time periods are recorded. Log books are intended to be used both at school and at home.

Description

A suitable sized book, with unlined pages can be made for each child. Decisions about headings also need to be made - such headings might include:-

Moon watching - draw up a chart to show the position and shape of the Moon over a month. A chart is provided at the back.

Sun and shadows - record the position of the Sun in the morning, the time it gets dark at night.

Other topics that could be included are exploration of space, the stars, poems about weather and seasons, other people's ideas about the Earth in Space, etc.

Follow up ideas

Some pupils might wish to extend their log book into a well presented topic book about the theme, rewriting and redrafting their initial entries and improving their presentation. They might attempt to describe some of the investigations they carry out without the direct supervision of teachers as well as the results of their own reading of information books. Conversations with family and friends outside school could also be recorded.

A7.12. Sundials and shadows

Explanation

Much of the work involving the Sun and shadows can be followed up within the classroom

using torches and objects which form shadows. Children should be encouraged to test out the ideas they have begun to form, through early observations of the position of the Sun in the sky and the lengths and positions of shadows.

Description

Children will need to make a simple sundial. This can simply be a stick in a plant pot. This can then be placed in the play ground and children can then mark the position and length of the shadow through the day.

This sundial can then be used on the next day to measure the time.

Children can also cut strips of tape to the length of the shadow during the day at regular intervals. These strips can then be made into a chart with one placed for each hour. If they missed one hour, they will have to leave a gap. This should give a good visual picture of the change in the length of the shadow through the day.

Follow up activities

A darkened area will be needed - this can be made in a shaded part of many classrooms, with careful positioning of screens and room dividers. A variety of small objects, figures, toy animals, models from the Lego box, etc. can be used. A torch can be used to simulate the Sun in different positions. Shadows are then observed, in terms of their length for different inclinations of the "Sun" and their positions at different angles of the "Sun". It might be simpler to start with the torch, object and screen (for showing the shadow more clearly) at the same heights, and moving the torch left or right to see which way the shadow moves. Then one might position the torch at different heights and examine the length of the shadows. Finally, one might attempt to combine both inclination and angle to simulate the apparent movement of the Sun across the sky.

A7b.13. Models of Sun, Moon and Earth

Explanation

In order to help children express their ideas about the relative movements of the Sun, Moon and Earth, it is useful to get them to act out such movements and then discuss their thoughts with each other.

Description

Pupils act out the movements of Earth around Sun and Moon around Earth, including spin and orbit. Children are asked to work in pairs. One child acts as the Sun and one child acts as the Earth. Children are asked to take it in turns directing the other and show each other how they think.

a) The Earth and Sun move in a day

b) The Earth and Sun move in a year.

After a pair has finished they could join with another pair and see if they agree.

Follow up ideas

One child acts as the Moon and the other acts as the Earth. The children are then asked to show each other how they move over 28 days. (The correct answer is the Earth should stay still and the Moon should move around once with its face pointing at the Earth all the time.)

A7b.14. Observing the Moon

This activity should encourage children to look at the night sky and make regular observations. The final charts can be compared or included in their scrap books.

Description

Provide the children with a copy of the chart and ask them to draw the Moon as they see it each night. If it is cloudy, they should record cloudy in the box.

Reading Activity 1

The system is made up of the Sun and all the objects that ______ ______ the Sun. The planets are the largest bodies that revolve around the Sun. The Earth is one of the nine known planets.

Planets are shaped like a ____ and move around the Sun. All the planets revolve around the Sun in the same direction. The path that a planet takes is called an ____. It takes _____ _____ for the earth to revolve around the Sun.

Mercury, the planet ______to the Sun, moves completely around the Sun every 88 days. Because it is closer to the Sun than the other planets, it does not travel as many miles to complete its orbit. It does not need very much time to complete one ________.

Pluto, the planet furthest from the Sun, takes about 250 years to complete one orbit.

Planets have objects which go round them called satellites. The moon is a _______ of the Earth. Many of the planets have more than one ________. Other planets have none.

Planets do not give off _____ on their own. Like the moon, planets ________light from the Sun. When you see a planet, you see the sunlight which is being reflected to you.

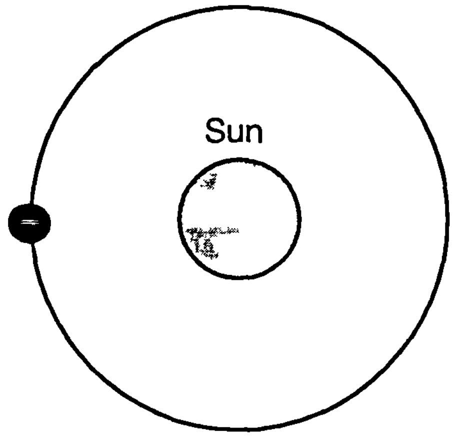
Instructions

Work in threes

1. Read through the passage.
2. Talk about what words could go in the blanks and fill in the words when you agree.
3. Underline all the words you do not understand.
4. Double underline all the words that tell you something about planets.
5. Make a list of all the words that are to do with moving.

Reading Activity 2

The _____travels around the Sun. It takes ___ _____ to go all the way around. This picture shows the path which the _____ takes as it travels around the Sun.



The Earth is ___ million kilometres away from the Sun. While the Earth is travelling around the Sun it is also _______ ______ like a top. It turns around ____ every __ hours.

The Sun can only shine on ___ ____ of the Earth at a time. It is daytime for that side of the Earth. The side of the Earth away from the Sun is in darkness. It is ____-_____ there. As the Earth spins around, the dark side gradually turns to face the Sun.

As our side of the Earth turns towards the Sun we begin to see the light from the Sun. We say that the Sun is ______. As we turn away from the Sun, the Sun seems to go _____ in the sky. We say that the Sun is _______.

Instructions

Work in threes

1. Read through the passage.
2. Talk about what words could go in the blanks and fill in the words when you agree.
3. Underline all the words you do not understand.

Reading Activity 3

The Sun and its planets together are called the **Solar System.** The Sun's nine planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto.

Mercury is the planet nearest to the Sun and Neptune and Pluto are furthest away. The planets are named after ancient Greek and Roman gods.

Mercury

Mercury travels around the Sun faster than any other planet. It takes 88 days. It was named after Mercury, who was the messenger of the gods.

Mercury is the smallest planet; it does not have any satellites. It is 58 million kilometres from the Sun. It spins around slowly, taking 59 days to turn round once. The side of the planet which faces the Sun is very hot, and the other side is very cold. It is much too hot and cold for anyone like us to live there. There is no atmosphere on Mercury as the Sun has boiled all the gases off.

Venus

Venus is a little smaller than the Earth and is 108 million kilometres away from the Sun. It shines very brightly in the sky and can be seen clearly with a telescope, sometimes even during the day. Venus was named after a Roman goddess.

Venus can never be seen very late at night. It is nearer to the Sun than we are, so when we turn away from the Sun we begin to turn away from Venus too. It is best seen in the early evening just after the Sun has set or early in the morning before dawn, and is often called 'the evening star' or the 'morning star'. It takes Venus 243 days to spin around once.

Venus is covered in a thick layer of clouds. They are not like our clouds. The clouds around Venus are made mainly of carbon dioxide, and it is impossible for us to breathe on Venus. Because of these thick clouds no one can see the surface of Venus.

Mars

Mars is smaller than the Earth and is 227 million kilometres away from the Sun. It takes Mars 687 days to travel around the Sun and just over 24 hours to spin round once.

It is easy to see the surface of Mars through a telescope because there are no clouds to hide it. Most of Mars is covered with sand and red rock and because of this it shines brightly in the night sky. This is why it is often called the 'red planet' and people think it looks angry. On Mars, dust makes the sky salmon pink in colour.

Jupiter is the next planet away from Mars.

Jupiter

Jupiter is the biggest planet. It is bigger than all the other planets put together and shines very brightly in the night sky. It was named after

Jupiter, the King of the gods. It is 748 million kilometres from the Sun and takes nearly 11 years to go round it once.

It is very cold on Jupiter. Poisonous gases swirl around it; the gases are ammonia and methane, and they look like coloured bands around the planet as it spins around. Jupiter spins around once every 10 hours. On one band there is a big, red spot. This spot was first seen in 1875, and its brightness changes from year to year. No one knows what the 'great red spot' of Jupiter really is but they think it is rather like a hurricane on Earth.

Saturn

Saturn looks beautiful through a telescope as it is surrounded by rings. Saturn was named after the Roman god of agriculture. It is smaller than Jupiter, but still very much bigger than Earth. It is 1,425 million kilometres from the Sun.

The rings around Saturn are made up of millions of pieces of rock and ice. They move round Saturn very quickly. Saturn spins around once every 10 hours. Saturn has many moons that spin around it.

Activities

1. Make a chart which will tell you many of the facts about planets that are in the piece you have just read. Your chart should have the planets down the side and headings at the top.

Working in groups, discuss what other information you would like to put in the boxes at the top.

Now read the passage again, underlining the information for each group you have. Use a different colour for each group.

What we know about Planets

	distance from the Sun
Mercury	
Venus	
Earth	
Mars	
Jupiter	
Saturn	
Uranus	
Neptune	
Pluto	

You will have to find the information about Uranus, Neptune and Pluto from books

2. Pretend that you are in a spaceship on your way to Venus. Your spaceship gradually gets closer and closer to the planet. It enters the thick clouds around Venus and comes nearer to the surface of the planet. You are the first person to ever see what Venus is really like.

Write down what you would say to people on Earth through your radio.

Tell them what you see and how you feel.

The Moon at Night

	Monday	Tuesday	Weds	Thurs	Fri	Sat	Sun
Week 1							
Week 2							
Week 3							
Week 4							

Appendix 8: Additional Papers

The following is a paper presented at the 3rd Conference on Learning Strategies and Misconceptions in Science, Cornell University, August 1993 which provides an extended version of the argument stated in section 8.8.

Beyond Constructivism

During the past decade 'Constructivism' or one of its many variants has become the dominant ideology in science and mathematics education and the grip that it holds on the research work in these domains is reflected in the almost exponential growth of research in this field (Duit, 1993). This paper is a critical exploration of the implications of this one dimensional approach and concentrates on the notion of Constructivism prevalent in science education as defined by the Generative model of learning (Osborne and Wittrock 1985), Driver's (1985) account of a constructivist approach to curriculum development and White's (1988) position on the learning of science. Further, some of the theoretical aspects of Constructivism as elaborated by Glaserfeld (1987, 1989) will also be examined.

Constructivism has its roots in a reaction against the naive inductivism and deterministic Piagetian developmental stage-model of cognitive growth. In developing its case it has focused very strongly on the resiliance of learner's beliefs and the social construction of reality. Inevitably, when these features are in focus, there are other features which are blurred and out of focus, if not out of the picture altogether. The concentration on these issues has led to the neglect of important epistemological and psychological concerns. Also, to the extent that the personal and social has been given priority over the obdurateness of the natural world, my contention is that there is a danger of a slide into relativism, if not idealism, and a devaluation of science through an overemphasis on the learner's inductive interpretation of phenomenological experience.

Thus, whilst versions of constructivism have had some limited pedagogic success, they suffer from basic epistemological weaknesses which will always restrict its potential as a theory of knowledge acquisition. In addition, constructivist psychology is currently an inadequate theory lacking a hard core of ontological commitments that enable it to be either tested, or assist in the development of successful learning strategies other than at a general or meta-level. Many of the learning techniques proposed by these and other authors also make assumptions about the preferred learning styles of students which research does not support. The result is that the narrow focus on this research paradigm will ultimately limit the development of an effective science education.

Instead, the case is advanced that the realist epistemology of Harré (1986) provides a structuralist view of knowledge necessary for the consideration of issues of development and progression within the curriculum and, that to combine this epistemology with a more organic view of learning which recognised science education as multi-faceted process and unique to each individual, would be more productive.

CONSTRUCTIVIST EPISTEMOLOGY

One of the fundamental tenets of constructivism is that cognition is adaptive and serves the organisation of the experiential world. For instance, the key postulates of the generative model of learning (Osborne and Wittrock 1983) are that:

- The learner's existing ideas influence what use is made of the senses and in this way the brain can be said to actively select material.
- Learner's existing ideas will influence what sensory input is attended to and what is ignored
- The input selected or attended to by the learner has no inherent meaning.

- The learner generates links between memory store and sensory input to actively construct new meaning.

Hence the learner must be active and exposed to a wide variety of sensory input from which they can construct personal meaning. But what is the nature of this sensory input and more importantly, how are new meanings constructed? On this matter, Osborne & Wittrock are notably vague stating that a teacher needs to 'provide opportunities for pupils to consider, contemplate and expand their views of the world' and to 'have new experiences and to ask questions'.

The emphasis placed by this model on sensory experience is an unfortunate one. For, whilst sensations are important in constructing descriptive and explanatory schema, particularly for the young child, the model fails to recognise that one of the most important means of generating new meanings is through a process of reflection and reorganisation of the internal symbolic representation of sensations. Hence Galileo's creative achievement was not his observations of pendulum motion, but his reinterpretation of the sensation of the oscillating pendulum as an idealisation in which the mass was concentrated at the centre and with no frictional forces acting, meanings which are not accessible by perception. The cultural capital of western scientific thought is these symbolic representations of experience and the key issue for science education is how these may be effectively acquired by students.

Secondly, the epistemology of science depends on both a methodological and ontological component. As Matthews (1992) and Suchting (1992) have both argued, the emphasis on sensation and experience in constructivist writing is in danger of reducing the methodological component to the epistemology of empiricism and inductivism which sees the scientific enterprise as one of investigating the world and trying to 'make sense' of sensations and experiences. For instance, writing in the UK Association for Science Education Handbook for Teachers, Asoko et al (1993) argue that 'learning involves the learner in making sense of things in terms of their existing ideas' though they do acknowledge that 'this will sometimes involve moving beyond their current interpretive framework to one which is better able to make sense of their experiences'. Similarly White (1988) argues that biology and Earth Science can be learnt by students concentrating on observing and describing. Only later would general principles be taught. Tobin, Butler Kahle et al. (1990) argue for a phenomenological approach based on extensive experience in science classrooms in which prior knowledge is elaborated and changed on the basis of fresh meanings negotiated with peers and teachers. Glaserfeld (1987) too argues that

> " The cognitive organism tries to make sense of experience in order to better avoid clashing with the world's constraints....Basically to have 'learned' means to have drawn conclusions from experience and act accordingly"
>
> (Glaserfeld, 1987, p 8.)

and

> "If our concepts are derived by abstraction from experience, there are no grounds for belief that they could capture anything that lies *beyond*[1] experience."
>
> (Glaserfeld, 1991, p31)

Taken literally, Glaserfeld's position would imply that the only accessible meanings are those of which we have direct experience, essentially the view of the logical positivists. Furthermore, it would appear to deny the role of language in the sharing of experiences and the negotiation and generation of common understanding. For instance, I know that South America exists, that it has a large river flowing through it called the Amazon etc. All of these pieces of indirectly obtained information enable the construction of a detailed geographical concept of a continent of which I have no direct experience such that, for myself and others, the ontological status is not in doubt.

In all these accounts, we find that considerable emphasis is given to the value of direct experience and observation, that is to an empiricist approach to learning science, and insufficient stress is given to the process of acquiring new frameworks for reinterpreting experience and transcending commonsense

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1 Von Glaserfeld's emphasis

reasoning. Though constructivist writers often qualify their position and acknowledge the role of language, there is an important distinction to be made between knowledge of real objects, accessible to experience, and knowledge of the theoretical structures we hold *communicated through language*, a nuance that continues to elide constructivism which places an emphasis on knowledge as a personally rather than socially constructed, yet alone recognise that it may exist as an objective entity in its own right - an objectivist view of knowledge elaborated by Popper (1972). The great success of modern science has come from individuals who have transcended intuitive reasoning and the experience of their senses to use their imagination to devise new ways of conceiving of how the world might be (Chalmers 1982). That is, from attributing properties *to* objects rather than drawing properties *from* the objects. Unfortunately the emphasis within constructivism on the subjective, personal experience and opportunities to 'make sense' emphasises the latter process rather than the former. The consequence is that empiricism casts a long shadow over the constructivist camp in education.

Driver herself does come near to confronting this issue when she states

> "The theoretical models and scientific conventions will not be 'discovered' by children through their practical work. They need to be presented. Guidance is then needed to help children assimilate their practical experiences into what is possibly a new way of thinking about them."
>
> (Driver, 1983 p 9)

But in her later seminal paper on a constructivist view to curriculum development, this matter is avoided as we are told that 'we can specify the experiences which students should be exposed to' but are given no principles on which to make such judgements other than 'knowing where students are starting from' and a reliance on the teacher's intuitive knowledge of classroom realities. The curriculum process itself contains an evaluation phase where pupils test a range of ideas 'including the scientific one if they have suggested it.' But what if they have not - on this issue the authors remain silent. Only Millar (1989) addresses the problem directly by arguing that in constructivism -

> "there is no ideological requirement to wait until pupils 'discover' the scientific idea themselves....classroom activities are organised to maximise student's opportunities to articulate their personal constructions".

However the basic epistemological weakness of constructivist theory is that it lacks any elaborated mechanism for theory adjudication which would assist the learner in the selection and evaluation of theories. The constructivist position is best elaborated by Von Glaserfeld (1989) who states that

> "knowledge cannot and need not be 'true' in the sense that it *matches*[1] ontological reality, it only has to be 'viable' in the sense that it *fits* with the experiential constraints that limit the cognising organism's possibilities of acting and thinking."
>
> (Glaserfeld, 1989), p 162.

The empiricist theories of children and adults which are the product of the application of commonsense and inductive reasoning are extremely 'viable' matching their experiential constraints very successfully. Therefore one of the roles of science education is to provide experiences which show that commonsense theories are an inadequate representation of reality but constructivism singularly fails to elaborate a mechanism by which one theory can be considered more 'viable' than another. The consequence has been a tendency by some writers to equate viability with validity so that any viable theory is considered worthy of consideration.

Most student's personal constructions, and for that matter adult ones, are fundamentally empiricist in their nature and extremely 'viable', but from a scientific perspective, erroneous. That this is so can be found by examining the vast body of literature on the topic consisting of books (Osborne and Freyberg 1985) (Driver 1983) (Driver, Guesne et al. 1985) (Black and Lucas 1993), articles (Gilbert and Watts 1983) and bibliographies (Pfundt and Duit 1988) (Carmichael 1990). Ideas and theories are commonly based on everyday observations out of which are formulated a set of 'scripts' (Schank 1982) or as has

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1 Von Glaserfeld's emphasis

been argued by di Sessa (1988), a set of phenomenological primitives. The common consequence is a lack of any coherent theory and a resort to contextualised observation, often resulting in conflicting explanations for similar observations (Osborne, Black et al. 1990) (Durant, Evans et al. 1989). Yet the problem for the constructivist is that there is no explication of how the 'viability' of these theories is to be refuted.

Additionally, it has led to dangerous attempts (McKinley, McPherson Waiti et al. 1992) to justify the inclusion of scientific traditions of other cultures on the basis that these are scientific enterprises as valid as the tradition of Western cultural science. Since much of this knowledge was derived by trial and error techniques driven by technological need and is profoundly empiricist in its origins, these constructivists are at least being consistent with their view of science as knowledge which is derived from experience. However, such science often lacks a theoretical base and this omission has severely limited its explanatory and predictive power, precisely the qualities that have made Western science so successful. This is not to say that such attempts at the scientific enterprise by other cultures should not be taught but that a social anthropological approach should be used which recognises the achievements of their scientific and technological endeavours and crucially, their limitations.

The third weakness, and for science educators possibly the most important, is that this relativist stance fails to recognise any distinctions in the complexity and difficulty of theoretical descriptions of real objects, or that some of the 'idealisations' of science describe concepts which are *not accessible* to sensation or experience e.g. energy, but have to be formulated through a process of reflective abstraction. Whether there are developmental limitations on children's capacity to undertake such reasoning is an issue that a constructivist epistemology ignores and the consequence is that it remains silent on the essential issues of sequencing and progression in the content of the curriculum. This failing is *a major omission* of constructivist theory in its application to education.

Consequently current interpretations of constructivism in science education, by placing emphasis on experience and sensations from which children are expected to 'make sense' are in danger of leading to an empiricist and relativist approach to the curriculum which ignores the fact that science education is of necessity a process of acculturation. This is not to argue that the process of education should be one of transmission, but simply that it must enable children to acquire and understand the powerful constructs and ideas of modern science and that any comprehensive theory of education should address the issues of content, concepts, sequencing, cognitive demand and the adjudication of competing theories. The epistemological weakness of constructivism is that it has little to offer the curriculum developer on these issues.

REALISM REVISITED

In contrast to the empiricist and relativist interpretations of constructivism, Harré (1986) argues for a modest position of 'referential realism' whose epistemology offers science education a position which at least enables it to define what might be an appropriate curriculum and possible pedagogy. Essentially his position is that there are three types of entities that we experience in the world which require not a *singular* theory of science but a *triadic* one. Realm 1 theories enable the classification and predictions about macroscopic objects which are tangible and accessible to sensori-motor experiences; thus a typical realm 1 theory is Newtonian kinematics. Realm 2 theories are iconic in the sense that they represent unobservable entities which are only accessible to our senses through instrumentation such as bacteria and viruses. The vast majority of scientific theories are descriptions and hypotheses of realm 2. Finally realm 3 theories describe theoretical objects for which there is no direct evidence of their existence such as quarks and black holes whose descriptions are essentially mathematical.

In arguing for a referential realism, Harré states that our interaction with, and sensory feedback from macroscopic objects allows us to know what the attributes of such entities are. Their ontological status is not in question but the notion that we ultimately can know the 'truth' about such objects is sensibly dismissed. Interaction, testing and feedback enable us to know more and he argues that the idea that the truth about an object, in the Platonic sense, could be known is a fruitless search. Therefore he argues for a realism based in material practice where scientists ask questions of the form 'Do things, properties, processes of this sort exist?' and then attempt to find exemplars within the limitations of technology. This form of realism is epistemically modest and makes no assertions that there are 'incorrigible existential claims'. All that it attempts to show is that the ontology of scientific investigation is relatively stable as opposed to the cluster of beliefs that we may hold about it.

Consequently what Lister observes as 'loose cells' in an infected wound and Pasteur describes as 'external agents of infection' exist and can be referred to through material practice. Referential relations and our descriptive vocabulary can be revised but the basic ontological sketch is not in question. For instance, the heart and the circulatory system existed before Harvey first described them in 1628.

Realms of experience

Experiences of such macroscopic objects are those which the child uses to construct explanatory schemas of physical and biological phenomena, albeit fragmented and lacking any theoretical description other than an intuitive mechanics (Mariani and Ogborn 1991), (Bliss, Ogborn et al. 1989), (di Sessa 1988) and an intuitive biology (Carey 1985). If so, an early science education should attempt to build on and extend children's experiences of macroscopic phenomena, introducing the child to the descriptive language of the scientist and the theoretical frameworks which enable them to generalise from such experiences. For as Harré argues, 'theory is a device for focussing our attention. Theory precedes fact....because a theory determines where in the multiplicity of natural phenomena, we should seek for *its*[1] evidence.'

Such an approach would encourage observational activities of a wide range of common macroscopic phenomena. For instance the fact that all liquids can be made to 'disappear' and 'reappear' and that such properties are what scientists call 'evaporation' and 'condensation'; that all animals have a mechanism for taking in oxygen and exhaling carbon dioxide; that springs and rubber bands stretch and that they a share a common pattern in the way in which they stretch. i.e. the sole purpose of such an education at this stage would be to enhance their descriptive language and to show that, with such a language, all phenomena are not uniquely contextualised but share universal properties. Moreover, such an approach would place a greater emphasis on introducing the theoretical description *prior* to observation and experience rather than a vain hope that the child might spontaneously discover the scientific explanation from an interpretation of their empirical data.

From here, science education would move to examine the theoretical entities of science for which there is instrumental evidence, Harré's realm 2 entities. Typically, this would require an exploration of the particle model and the evidence to support it; the evidence of microscopy for the internal structure of plants; the evidence of dissection or models for the internal mechanisms of the body; the evidence for charged nature of matter, the nature of the Solar System, etc. All are entities whose ontological existence is inferred from the evidence of instrumentation. However, their existence can be directly related through such evidence to realm 1 macroscopic objects and these are entities of possible experience.

Realm 3 entities are the abstractions of the human mind for which there is no instrumental evidence. As such these entities are inferred to explain certain experimental results - the neutrino and quarks are both classic examples. However at a more mundane level, quantities such as speed, acceleration, current, charge, energy, the mole, molecular biological mechanisms are such abstractions. These concepts can only be constructed on a sound scientific understanding of realm 1 and 2 entities. Hence the idea of speed is constructed out of the pupil's experiences of motion and the measurement of time and distance, both realm 1 entities; the idea of current constructed from observations of the brightnesses of bulbs and simple causal relationships. Cognitively such ideas are more demanding because they require the ability to envisage and manipulate imagined entities and their symbols for which there is no direct referent.

Immediately such an interpretation of scientific theory accounts for two of the current problems within science education. Firstly since much of modern science provides explanations of realm 3 entities, there is a natural inclination to a relativistic stance which forgets the grounds on which such theoretical objects are formulated. Secondly, in science education, we have attempted to ontologically shift some entities such as energy from realm 3 to realm 1 with a failure to address the inevitable problems that arise out of attempting to make the intangible, concrete and self-evident.

More importantly, this epistemology would provide an improved interpretation of science to that of the constructivists. Firstly because it would avoid the relativist pitfall of the radical constructivist who would ascribe validity to any 'viable' theory that encapsulated personal experience. More importantly,

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1 Harré's emphasis

it would enable the curriculum developer to make decisions about content, a matter on which a constructivist epistemology says nothing. Yet quite plainly we choose not to teach children about special relativity, quantum mechanics, molecular biology and the electronic configuration of chemical bonding because we know that such knowledge is not accessible to them till they have understood a wide body of other factual and theoretical information. The epistemology of constructivism provides no reason why this should, or should not be done. In fact, empiricist interpretations of constructivism would almost deny such an understanding to pupils as the capacity to abstract from experience and develop such concepts requires a supreme intellectual effort of which historically only very few are capable.

The problem of the determination of content is compounded by the fact that the theoretical base in Ausubelian psychology and that of Kelly has never been developed into a model which would enable predictions to be made of what material will or will not be accessible to learners. The much quoted statement of Ausubel (1968) is essentially nothing more than a statement of good common sense and the success of constructivism has come from reminding teachers that children are not atheoretical subjects and that their thinking is the foundation on which new meanings must be formulated. The generative learning model developed by Osborne & Wittrock (1983) suffers from the similar criticisms and is ultimately a restatement about the nature of perception developed by Hanson (1958) and Polyani (1958). The most serious criticism of the constructivist theory is that it provides no well-defined mechanism by which the individual can develop new constructs with which to see the world. From whence come the ideas with which the individual is to interpret their sensory perceptions? Where for instance is the role of analogy and metaphor which are the vehicles for extending our thinking and ideas and reorganising our internal symbolic representations? For example, to observe Brownian Motion in a smoke cell a student has to be provided by a teacher with a construct which will enable them to make sense of their perceptions prior to observation. This can only be done through the use of a taught analogy or comparison. Without this, the common experience is that the student's attention is needlessly focused on other elements in the microscope.

Research shows that the commonly proposed model of 'cognitive conflict' as a mechanism for the production of new knowledge is at best only a partial solution (Rowell & Dawson, 1983), (Cosgrove, Osborne, & Carr, 1984), (Gauld, 1989). Reformulation of sensation will only occur by reflection and reorganisation of the representations, something which Cosgrove et al acknowledge when they state

> 'We are increasingly aware that conceptual change takes time and that it is important that counter-intuitive ideas are considered at regular intervals over a period of time.'
>
> (Cosgrove et al, 1984, p 254)

Additionally, this perspective requires a consideration of whether the student has the cognitive tools to undertake the manipulation of symbols and whether there is age-related development in such facilities - a developmental perspective which is totally omitted from constructivist accounts of learning.

Faced with the problem of the determining content, one can only conclude that constructivism has eschewed the issue. Instead, they have resorted to an individualistic approach, arguing that opportunities must be provided for the learner to externalise their understanding and this must then be challenged by critical incidents which generate conceptual conflict (Driver and Oldham 1985) in such a manner that the new ideas are 'plausible, intelligible and fruitful' (Hewson and Hewson 1984). Given that all the major ideas of science, from the basic idea that the Earth moves around the Sun to the idea that the speed of light is invariant with the speed of the observer, are not commonsense interpretations of experience but in essence unnatural (Wolpert 1992) this could be regarded as an act of self-deception reflecting a failure to understand the nature of science.

CONSTRUCTIVIST PEDAGOGY

If constructivist epistemology is seriously flawed then surprisingly perhaps, constructivist pedagogy has had some successes. The strong message of this body of research has been to expose the difficulty large numbers of children experience in internalising the explanatory models of science and applying them correctly. Such data has inevitably raised the dilemma of how to respond to this evidence and since student difficulties were inevitably the product of conventional pedagogy of a didactic or 'guided discovery' nature, the challenge was to devise an approach that was distinctive with a different emphasis.

Didactism places the focus and responsibility for learning on the teacher, examining the quality of their explanation, the use of analogy, the appropriate use of language and the effective use of apparatus and other materials particularly for experimental demonstrations all for the purpose of transmitting a body of knowledge. Constructivists rightly turned their attention to the learner arguing correctly that the learner is responsible for their own learning (Osborne and Wittrock 1985), (Novak and Gowin 1984), (Pope 1985), (White 1988). Here, after all, in the learner's mind, was where new meanings had to be formulated and understood. This could only be achieved if the learner was an active participant in the learning process. Hence, their pedagogy has concerned itself with formulating a programme of activities from which knowledge can be formulated or acquired. These tasks focus on the learner, asking the individual subject to articulate and use their reasoning in a set of structured exercises. In all of these activities, they have implicitly or explicitly placed their belief in the idea that language is socially constructed and that many words are signifiers for concepts or referents. An understanding of the concept signified only comes through the opportunity to practise and discuss the appropriate use of language in the relevant context. Or as Vygotsky (1986) puts it-

> 'The development of the scientific concept, on the other hand usually begins with its verbal definition and its use in non-spontaneous operations - with working on the concept itself.'
>
> (Vygotsky, 1986, p 192)

Constructivism has encouraged teachers and curriculum developers to alter their perceptions of children from epistemic subjects who are atheoretical and unknowing to cognisant individuals who have well-developed theories. Formal elicitation of this knowledge as proposed by Driver and Oldham (1985) becomes important for two purposes - to encourage the child to clarify and articulate their own understanding and as a process of formative assessment by the teacher to ascertain the teaching and learning needs of their students. Many of the earlier schemes made good use of group discussion and poster making for such purposes (Nussbaum and Novak 1981) (Cosgrove, Osborne et al. 1984) (CLIS Project 1987) and such processes enable the social construction of meaning. Further work by many researchers in the field has led to the production of a wide range of structured techniques that require the active participation of the student and one recent book (Baird and Northfield 1992) gives details of more than 80 such techniques. Notable amongst these structured strategies are predict-observe-explain sequences (White 1988), further elaborated in White and Gunstone (1992); discussion of instances of physical phenomena (White and Gunstone 1992); concept mapping (Novak and Gowin 1984); word association (Shavelson 1974) and active reading techniques commonly called DARTS (directed activities related to text) (Davies and Greene 1984). Though neither of the later two strategies were the product of an explicitly constructivist approach to pedagogy and currently, there is only limited research evidence for the value of any of these approaches. For instance in a recent meta-analysis of 18 studies of concept mapping that met strict criteria of well-defined experimental models with controls, Horton (1992) found 16 of the studies produced positive learning gains for the experimental groups. For the sake of establishing their case, more empirical studies of this nature are essential to justify constructivist approaches to teaching and learning.

White (1988) has probably made the most effective approach to derive a theoretical base for a constructivist pedagogy and psychology relevant to science education. His approach is essentially that of the schematists who see knowledge and its organisation as a hierarchy of schemas induced from experience. From this perspective, highly content specific schema are overlain by progressively more abstract and general ones. In his analysis of the acquisition of knowledge and understanding, he argues that there are seven types of memory elements: strings which are learned by rote; propositions which are the description of concepts and statements of their relations; images which are retained mental pictures; episodes which are records of our experience; intellectual skills which are a modified subset of the intellectual skills proposed by Gagné (1968); motor skills and cognitive strategies which he conceives of as a set of identifiable and learnable skills, each of which can be applied to a specific task. Thus unlike propositions and intellectual skills, cognitive strategies are not subject specific but a powerful set of general purpose procedures which include the ability to analyse, reflect and generalise. White acknowledges that these strategies are difficult to elaborate and study but that our expectations should be limited as only a small amount of research has been undertaken. He sensibly concludes that a perspective that argues for the importance of cognitive strategies requires schools to turn from sifting knowledge and attend more to its production. In a world, where didactism is still the essential model of teaching and learning, the case for such an argument is incontrovertible.

What is omitted from White's and the other constructivist accounts of learning is an attempt to relate specific strategies to a general theory of learning. For instance, the term 'metacognition' is used to describe the thinking generated by active learning. Yet the lack of any theory that adequately describes such activity inevitably leads to more unanswered questions. Are all pupils capable of metacognitive activity or just some? Is there a critical age below which children can not be metacognitive? Is all such activity beneficial? To the latter question applied commonsense answers 'yes', yet such a response exposes the weakness of the psychology of constructivist pedagogy. Is there anything more to it than the notion that the pupil should be active - a thinking metacognitive subject?

At this juncture, the question of content inevitably re-emerges, for the question that needs to be asked is 'meta-cognitive about what?' To the teacher and the curriculum developer such decisions are the bread and butter of their daily lives as they attempt to order content to form a coherent introduction to science and select material which stimulates but is not overdemanding. On this issue, constructivist accounts of science education have nothing to say other than the familiar Ausubelian refrain.

STYLES OF LEARNING

Finally, there is another critique of such a single-minded approach to teaching and learning which needs to be considered. Essentially this is that students differ in their preferred learning styles and strategies and, just as an over-reliance on a didactic style can be unappealing to some students, so can an over-reliance on the techniques of a constructivist pedagogy which place an emphasis on co-operative, discussion-based activities for the production of knowledge. Such an approach to learning is preferred by some, but not all students, and likewise, is effective for some but not all.

The literature on learning styles is extensive. Brophy and Good (1974) explored the effects of diverse cognitive styles and personality characteristics whilst Good and Power (1976) examined the effect of affective characteristics e.g. attitudes, interest and motivation. However, some of the most interesting work has been undertaken by Pask (1976) and Entwistle (1981). Pask identified two main types of learning strategy used by different individuals: 'the serialist' who deployed a step-by-step strategy which examined one hypothesis and then the next in a simple linear progression, and in contrast, the 'holist' who took a more global approach to problem solving, considering multiple-hypotheses simultaneously and used a more individualistic approach to learning. Pask found that both groups of students were capable of reaching the *same* level of understanding but that their ways of attaining that understanding were *very different*. Holists prefer to start by forming an overall picture of what is being learnt whilst serialists attempt to integrate separate topics in a piecemeal form. Hence whilst the holist is concerned with comprehension learning, constructing descriptions of 'what is known', the serialist takes an operational approach attempting to master procedural details.

One of the most important experiments conducted by Pask, which those who wholeheartedly advocate a constructivist pedagogy should note, was to match and mismatch sets of learning materials with student's learning styles. The students in the matched conditions were able to answer most of the questions about what they had learned, whereas the mismatched students generally fell below half marks.

Entwhistle's work explored the personality factors that correlated with academic success in undergraduates. He identified three distinct personality types whose approaches to learning were all significantly different. The first group were motivated students who were emotionally stable and were spurred by competition to demonstrations of intellectual mastery. The second group were the antithesis in that they were unrealistically pessimistic about their ability and haunted by the fear of failure. Driven by anxiety, these students had unconventional, though effective, approaches to studying. The final group were predominantly arts-based students and combined high verbal aptitude with good study methods and long hours of study.

The important conclusion to be drawn from this research is that students vary in their motivation and preferred learning styles and that a teaching scheme based on a single perspective will only meet the needs of a subset of any group of students. Within science education itself, there are a number of studies which support such an interpretation.

Kempa and Martin-Diaz (1990a) (1990b) in a study of 390 Spanish 15 year olds identified four types of motivational patterns in students who may be motivated out of a desire to either a) achieve, b) to satisfy their curiosity, c) to fulfil or discharge a duty or d) to affiliate and interact with other people. These he calls respectively 'the achievers', 'the curious', 'the conscientious' and 'the social'. Using an 80 item Likert-type preference inventory, he then examined the relationships that existed between these motivational patterns and their liking different instructional procedures. The main findings are summarised in Table 1.

Instructional Procedure	Motivational Trait			
	Achievers	**Curious**	**Conscien-tious**	**Social**
Knowledge Acquisition Mode				
Didactic Teaching	-	-	+	-
Use of Books		+ +	- -	
Discovery Learning	+	++		(+)
Working Arrangements				
Individual Work				- -
Group activity			(+)	+ +
Practical Work				
Doing Practical Work		+ +		(+)
Experimental work with instructions		_ _	+ +	
Organisation of Teaching				
Opportunity to pursue one's own enquiry.	+	+		++
Evaluation				
Teacher assessment			++	
General dislike of being tested				++
Risk-taking		+		

Table 1: Summary of relationships between students' motivational traits and preferences for instructional procedure. (Strong preference are indicated by '++'; '--' denotes the opposite. Moderate preference trends are indicated by '+'; '-' denoting moderate dislike. (+) indicates a moderate preference trend due to an indirect, rather than a direct relationship between preference and motivational trait.)

A constructivist pedagogy and its metacognitive activities rely heavily on practical activities (non-experimental) undertaken in groups. An examination of the table shows that such activities appeal to the social and partially to the conscientious and achievers but not to all. Further evidence that this is so can be found in the report of the PEEL project where a pupil comments:

> "It's about us learning about, and comprehending the work that teachers set....help students learn better by revising the day's work, and writing down in your diary what you have done....I didn't like doing it - I stopped about the second week we did it - it wasn't interesting"
>
> (Baird and Northfield, 1992, p 57)

That not all pupils find such an approach to their liking is important as this implies that *there is no one* strategy that will achieve success with all pupils. Kempa and Martin-Diaz argue that the only practicable solution to this problem is for teachers 'to use *as wide a range* [1] of instructional procedures as possible, instead of limiting themselves to one or two.' Yet the danger in constructivist pedagogy is an assumption that it offers an improved learning strategy for all pupils. Its major strength lies in offering an alternative - challenging teachers wedded to a didactic model of transmission by offering variety and diversity.

Further evidence for this view that varied approaches are needed to meet differing individual needs and topics is to be found in the work of Muthukrishna, Carnine et al. (1993). They point to the fact that in a number of studies that address 'alternative frameworks' directly, the success rate in changing children's ideas, which ranges from 28% to 69%, is limited and argue that their research, using an approach based on explicit instruction with a laser videodisc, which eliminated over 90% of common alternative frameworks shows that the 'common hypothesis that meaningful learning can not result from explicit instruction may possibly be an overstatement'. Whilst their work can be criticised on the basis that the domain of earth sciences has little possibility of generating many strongly-held intuitive ideas, it does show that not all science education requires a singular approach.

Therefore the evidence from research on learning styles argues that there is *no single, effective method* for teaching and learning as students differ in their preferences. From a psychological perspective and a careful examination of the aims of teaching science, Claxton (1993) argues convincingly that a single-minded emphasis on conceptual development in science is inappropriate for all children. Instead science education should be 'developing a wide repertoire of teaching methods that are custom-built for different aims and different clientele'. Consequently the only tenable position to hold in science education is one which sees it as an organic process where the epistemic biography of each individual is unique and also, uniquely determined.

CONCLUSIONS

No doubt there will be many who will dispute the many points made in this critique. Some will find the notion of a realist epistemology per se difficult to accept, even a referential one. For others its clear relationship to the structuralism of genetic epistemology will engender doubt in many minds. However the essential point is that there are essentially three sources of human learning which are a) daily experiences of the world, b) specialised experiences provided by institutions such as schools and c) culturally transmitted knowledge and information. Constructivist research has been seminal in exploring the learning outcomes resulting from the first category and begun to explore the nature of the experiences that would enable the student to reinterpret their experience from the standard scientific world view. However, it has ignored the important role of the third category and in doing so fails to acknowledge sufficiently the critical part played by theoretical constructs in reinterpreting experience. From whence are students to gain such understanding? The unfortunate tendency within much constructivist writing to emphasise sensation and experience, coupled with a relativistic view of knowledge, can give the impression that it will emerge magically from a process based on a form of Baconian empiricism where children make sense of their experiences. The argument made here is that a flawed epistemology will inevitably lead to a flawed pedagogy.

Hence we read in the UK Association for Science Education Teacher's Handbook (Ramsden and Harrison 1993) that teachers must start by 'finding what the learner's knowledge and understanding are' and give them 'opportunities to actively test and refine...their understanding'. Yet in the long list of learning activities e.g. raising questions, making observations, using practical skills, small group discussion etc, not one mention is made of an activity which would enable students to be provided with a scientific theory. Yet as Hodson (1990) so elegantly argues-

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1 Emphasis added

> 'the simple matter is that theoretically uninformed observations *do not*[1] and *cannot* lead to the acquisition of new concepts. The claims for theory-free experimentation are nonsensical on both epistemological and psychological grounds.....In short, theoretical considerations must *precede* experimental enquiry.'

However, since the reality of the classroom experiences throughout the world is predominantly didactic (Lewin 1993), many would argue that constructivist pedagogic practices are a valid attempt to redress and extend the balance and mixture of learning experiences for students. The evidence for such an argument is irrefutable and there are some sound psychological arguments for attempting to build on the learner's existing knowledge (Ausubel 1968). However, the uncritical adoption of constructivism has led to the evolution of arguments which attempt to deny the value of some didactic processes to some students, an epistemology which has no statement to make about developmental sequences or curriculum content and a pedagogy which lacks an adequate theoretical underpinning. Thus at times, it is hard to escape Suchting's (1992) conclusion that for some 'certain words and combinations of words are repeated like *mantras*[2] producing a feeling of enlightenment without the tiresome business of intellectual effort'. However, an improved science education will only come through the critical review of arguments and research evidence and by the adoption of a pedagogy which places a value on variety and diversity and not on a singular ideology.

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1 Hodson's emphasis

2 Suchting's emphasis

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